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INTRODUCTION

Many wholesalers, commission men, and other buyers in Massachusetts produce markets have frequently stated that vegetables being shipped from California and the South often arrive in the local markets in better condition than locally grown produce. Most of the shipped-in vegetables are harvested nine to fifteen days before they are sold as compared with local vegetables which usually are sold in less than twenty-four hours after harvest.

The paradoxical situation of freshly harvested vegetables being of lower quality than week-old produce may be attributed to the manner in which the commodities are handled and refrigerated. Out-of-state growers rely heavily on refrigeration to protect produce from spoilage.

The practice of using crushed ice in handling and marketing certain vegetables in Massachusetts is relatively new. Precooling vegetables with ice and package icing of vegetable containers are undoubtedly two of the most controversial issues among local vegetable growers and produce handlers. Most of the discrepancies have arisen from lack of valid information on crushed ice as a vegetable refrigerant.

Vegetable growers regard the use of ice with a range of attitudes extending from straight pessimism to definite enthusiasm. Some growers consider refrigeration of local vegetables to be an unnecessary refinement. They argue that local market gardeners are close to markets and that refrigeration is not required.

Many investigators have found that certain vegetables undergo considerable deterioration when exposed to high temperatures for one or two hours. Although the time required to market local vegetables is rarely more than twenty-four hours, some commodities, when not handled properly, become unmarketable during this time interval.

If a vegetable farmer decides to use ice in packages, he is immediately confronted with a number of questions. It is necessary for the grower to know the grades of crushed ice that are available and what the relative refrigerating efficiencies of these grades are. Another important factor for a market gardener to consider is the quantities of crushed ice required to properly refrigerate various sizes of vegetable containers. The method of distributing ice in a box or crate frequently governs the success or failure of package icing. A less obvious consideration is the manner in which iced packages are loaded on trucks. Farmers frequently become interested in using ice for precooling produce and they desire to secure information on this subject.

The object of this investigation has been to secure valid information on the use of crushed ice for refrigerating locally grown vegetables.

REVIEW OF LITERATURE

The literature on ice refrigeration of vegetables is extensive. Only pertinent material which is directly related to the several aspects of this project will be reported.

A review of certain factors influencing ice refrigeration will be considered first.

Raber and Hutchinson (52) define refrigeration as transfer of heat from a location where its presence is undesirable to a place where it is unobjectionable. They note further that ice collects heat by melting and transports it by drainage of meltage water.

Heat is assigned units of measure. Truscott (64) states that a common constant is the British thermal unit. This he defines as the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at normal atmospheric pressure (14.7 pounds per square inch).

Arnold (6) distinguishes between heat and temperature. He points out that temperature is the condition of a body which determines transfer of heat to or from other bodies, while heat is a basic form of energy.

Platenius (48) emphasized the fact that refrigeration from ice is dependent upon the rate of meltage.

It was reported by Scates (59) that the rate of ice meltage is not directly proportional to heat content of air, but depends upon transfer of heat from air to the ice surface. This observation was substantiated by Willis, Short and Woolrich (65) who found that ice meltage rates increase with an increase in relative humidity of air as well as an increase in air velocity.

An explanation of amounts of heat absorbed by melting ice is offered by Arnold (6). He notes that the surface of ice must attain a temperature of 32°F. before meltage takes place. In this discussion, Arnold (6) declares that a pound of ice absorbs 144 B.T.U. to change physical state to water. Thus a pound of water at 32°F. contains 144 B.T.U. more than a pound of ice at 32°F. When ice melts 144 B.T.U. of heat are absorbed to change physical state of ice to water, thereby producing the cooling effect.

Cardinell (12), in experiments with refrigerator cars, found that the more surface that air contacts in passing through a mass of broken ice, the greater is the amount of heat absorbed by ice. He concluded that small sizes of crushed ice present more surface in contact with air than large sizes, and hence lower the temperature of surrounding air more rapidly.

Humidity is a basic consideration in ice refrigeration. Relative humidity is defined by Rahm (53) as the ratio, expressed as a percentage, of the actual partial pressure of atmospheric water vapor to the saturation pressure of vapor at any given atmospheric temperature. McDermott (30) explains the relationship between temperature and humidity in more detail. He notes that by cooling a vapor but maintaining it under a constant pressure, a temperature is reached where this pressure is maximum. He terms this the point of saturation and declares that further cooling will result in condensation. Anderson (2) elaborates on McDermott's (30) statement and points out that the absolute quantity of vapor in the air is not important in evaporation, but rather the relation between amount of vapor present and amount that could exist under the same conditions without having condensation.

Relation of Temperature to Deterioration of Certain Harvested Vegetables

Platenius (47) found close correlation between temperature and resulting spoilage in vegetables. He reports that in general, rate of deterioration increases with an increase of temperature. This worker maintains that increment in rate of deterioration is more rapid in the low than in the high temperature range. Platenius (47) elaborates on this by noting that lowering temperatures by a unit of degrees in the temperature range above 55°F. has very little effect on total storage life of vegetables. On the other hand, a same unit decrease in temperature in the range below 55°F. increases storage life appreciably. The following year Platenius (48) conducted extensive marketing studies on lettuce and found that rate of deterioration was not proportional to temperature. He found that unless handling practices would reduce temperature of heads to 50°F. or lower, they were of little value in preventing deterioration. In keeping with his previous work (47), Platenius (48) indicated that savings in lettuce spoilage losses became progressively higher as lower storage temperatures were maintained.

Appleman and Arthur (4) confirm observations by Platenius (47) when they note that between 0° and 10°C., increase in rate of sugar loss in sweet corn is considerably greater than increase in rate of sugar loss in the range 10° to 30°C. Pentzer (42) also found similar relationships when he noted that a temperature rise from 68°F. to 86°F. increased sugar loss in peas only 1.4 times while in the lower temperature range, a rise from 32° to 50°F. increased sugar loss 27.5 times.

Two sources of heat have been described by Pentzer, Wiant and MacGillivray (41). These workers state that field heat is that heat initially acquired in the field. They assert that the second source of heat, vital heat, results from metabolic processes going on in plant tissue. Rose et. al. (57) note that vital heat is produced mainly by plant respiration. In a later paper, Pentzer (42) declares that plant respiration is characterized by the following chemical reaction: $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + 673$ kilogram calories. He emphasizes the most important feature of this reaction is 673 kilogram calories of heat which is liberated per gram molecule of sugar.

It has been pointed out by Rose et. al. (57) that amount of heat released in plant respiration increases as storage temperature increases. They note, for instance, that sweet corn stored at 32°F. liberates 6,560 B.T.U. per ton during a 24 hour period. When corn is stored at 40°F., heat of evolution is elevated to 9,390 B.T.U. per ton per 24 hours. At 60°F., the respirational heat rises to 38,410 B.T.U. Finally, at a storage temperature of 80°F. the heat evolved from a ton of sweet corn during 24 hours is 61,950 B.T.U.

Platenius et. al. (46) conducted cold storage experiments with several vegetables and noticed that temperature inside crates averaged 2 to 5°F. higher than temperature of cold storage rooms. He attributed this temperature difference to respirational heat of the vegetables.

Lewis (26) noticed heating occurred when bunched root crops were packed in closed containers.

Fisher (17) reports that the rate at which sugar reserves of vegetables are consumed depends upon rate of oxidation through the process of respiration. He states that the rate at which respiration proceeds depends largely upon temperature. Fisher (17) asserts further that rate of respiration in vegetables is approximately doubled by each 18°F. (10°C.) rise in temperature up to 110°F. Platenius (47) designates the number of times that respiration increases each 10°C. the temperature coefficient (Q_{10}). He explains that if respiration is doubled, Q_{10} is 2. Thus temperature coefficients as computed by Platenius (47) indicate degree to which deterioration is accelerated in vegetables and do not measure actual rate of deterioration at any given temperature.

In storage experiments with lettuce, McKenzie (31) noted a 6.33% weight loss after 48 hours of storage at 77°F.; a 1.28% loss after 60 hours at 40°F., and a 1.21% loss after 63 hours at 32°F. He found a close correlation between temperature and deterioration and concluded that the loss of weight was five times greater at 77°F. than at 32°F.

Platenius et. al. (46) also made studies on storage of lettuce and concluded that lettuce would remain in salable condition only 6 days at a storage temperature of 50°F., but would remain marketable 20 days when stored at 40°F. He found that storing lettuce at 32°F. kept this commodity salable for 30 days. In later studies, Platenius (48) investigated lettuce moving through New York markets. He stated that shipments which varied from 76 to 81°F. in transit had undergone 32.9 to 45.6% deterioration in 24 hours. Contrasting this, shipments averaging 47°F. in transit had undergone only 14.0% deterioration.

Mehren, Morris and Calhoun (32) found that a low temperature resulted in prolonging storage life of most vegetables. They reported that spinach remained in marketable condition only 2 to 3 days at 70°F., 5 to 6 days at 50°F., and 10 to 20 days at 32°F. Lettuce was found to have much the same keeping qualities as spinach at the temperatures noted. Topped carrots remained marketable 5 to 15 days at 70°F., 20 to 40 days at 52°F., and 60 to 90 days at 32°F. Asparagus was more sensitive to high temperature since it remained salable only 2 to 3 days at a storage temperature of 70°F., 5 to 8 days at 50°F., and 15 to 25 days at 32°F.

In a later report, Platenius (49) noted that some vegetables develop surface pitting at low temperatures.

Platenius (49) mentioned that this injury might result from abnormal respiration. Nelson (35), however, explained low temperature injury on the basis that oxygen absorption proceeds much faster than elimination of carbon dioxide in plant cells with the result of incomplete oxidation in the cell. This, he maintains, results in formation of toxic substances which cause injury or death to the protoplast.

Carolus (13) noted low temperature injury on several vegetables. He stated that green or pink tomatoes fail to color properly when stored at temperatures below 45°F. He observed that peppers, cucumbers, and snap beans developed sunken areas at temperatures below 40°F. and attributed this damage to disintegration of epidermal cells.

Rose et. al. (57) found that vegetables deteriorate more rapidly if they are first cooled and then placed in a warm storage, than if they had not been subjected to initial cooling. Appleman and Smith (5) were more cautious when they stated that the effect of previous cold storage on respiration and deterioration varied with different vegetables. These investigators noted that those vegetables in which percentage starch was high were the ones exhibiting the greatest initial respirational rates when transferred from low to high temperature.

Effect of Humidity on Deterioration of Certain Harvested Vegetables

Many investigators, (14), (46), (57), (58), (67) have emphasized the importance of maintaining proper humidity conditions in vegetable storages.

According to Rose et. al. (57) humidity of air surrounding vegetables has a direct relation to their keeping or storage quality. These workers specify that the most desirable moisture condition is that in which humidity of air is maintained at approximately the moisture content of the particular vegetable being stored. In a more detailed discussion, Rose et. al. (57) recommend that leafy vegetables and root crops be stored in a relative humidity of 90 to 95 percent; and most other vegetables be kept at 85 to 90 percent. Platenius et. al. (46) in transpirational studies, found that shrinkage rate was higher for leaf crops than root crops and stated further that large roots lose less weight than small ones on a percentage basis. These investigators concluded that vegetables which present a large transpiring surface to air such as lettuce and celery, suffer more wilt than vegetables with a small transpiring surface exposed, such as carrots and squash. Ruetenik (58) also found the same relation between transpiration in leafy vegetables and transpiration in more solid types of vegetables.

Comin (14) observed that when vegetables reach the temperature of surrounding air, relative humidity is responsible for practically all moisture losses, and temperature has only a secondary effect. Brasher et. al. (9) noted that moisture loss in harvested vegetables is noticed most commonly in weight reduction. They reported that since many vegetables are sold by weight in retail stores, loss of plant moisture becomes of considerable economic importance.

Hasselbring (20) inferred that practically all weight loss in vegetables results from moisture loss. We noted that loss of solid matter in carrots after storage for 22 weeks constituted only 1% of total weight loss, and 25% of loss was attributed to moisture reduction.

In his study of weight losses in carrots held under home conditions, Nylund (36) found that after 137 days of storage, topped carrots lost 27% of original weight when stored at 36°F. The weight loss increased to 48% when carrots were stored at 42°F., and 98% when kept at 50°F.

That vegetables lose weight most rapidly immediately after harvest, was pointed out by Ruetenik (58). He found that leaf lettuce stored at 32°F. and 95% relative humidity lost 3.7% of total weight in the first eight days of storage. Following this eight-day period, 14 additional days passed before another 3.7% weight loss occurred. Temperature and humidity conditions were maintained at the same levels as during the first storage period.

Patton and Miller (38), working with eight different vegetables, observed rapid loss in weight in all vegetables at room temperature. These investigators noted that weight loss was somewhat reduced when vegetables were stored in artificial refrigeration, and found no loss of weight when vegetables were packed in crushed ice. In addition, they observed that most of the vegetables packed in ice gained about 4% original weight. Doty, Hivon, Lewis, and Redfield (16) found that loss of weight in tomatoes was only slight when they were stored for four days at room temperature. Asparagus, however, was found to lose nearly 50% of its harvest weight in six days when stored at room temperature.

Kays (24) observed differences in weight loss between ice refrigerated and non-refrigerated vegetables. This worker found that after six days of storage, asparagus imbedded in ice lost 0.6% moisture while an uniced lot at room temperature lost 2.2% moisture content. This loss is considerable less than that found by Doty et. al. (16). Kays (24) found that iced sweet corn lost only 0.3% moisture in a 6 day period while uniced corn lost 22.9%. Lots of iced spinach lost 0.4% moisture during six days of storage while uniced lots lost 7.6%.

In experiments with celery, Work (66) found that after six days of display on an open counter at 60 to 62% relative humidity, weight loss was 39.6%. Under ice refrigeration with relative humidity of 70%, weight loss was only 12.4%. Platenius et. al. (46) also worked with celery and recommended that relative humidity for storage of this crop should be 90 to 98%. These workers noted that celery was extremely sensitive to moisture conditions and would wilt if relative humidity dropped much below 90%.

Platenius and Van Doren (50), and Pyke and Allison (51) have observed that slimy molds attack vegetables which are moist and are held at room temperature. Pyke and Allison (51) emphasize the importance of supplementing high humidity storages with refrigeration.

Precooling Vegetables

Precooling is defined by Hienton and Fawcett (22) as a form of refrigeration used to rapidly lower temperature of a perishable product before shipment.

Platenius (47) and Rose et. al. (57) have emphasized that deterioration processes in vegetables occur most rapidly during the first few hours after harvest. Pentzer et. al. (40) and Rear (54) note that one of the primary objects of precooling is fast removal of field heat from vegetables.

Lincoln (27) and Rear (54) indicated that produce may be harvested when fully mature and shipped without danger of spoilage provided vegetables have been adequately precooled. Fisher (17), Hienton and Fawcett (22) and Perry (43) have pointed out that precooling guards against decay and spoilage while vegetables are in transit.

Fisher (17), Pentzer et. al. (40), and Perry (43) note that precooling eliminates the necessity for large amounts of refrigeration during subsequent shipment. Fisher (17) adds that precooled products are frequently iced only initially and declares that without precooling, perishables would require supplementary icing in transit.

The fact that cooling involves time has been stressed by Rear (54). He emphasizes that precooling is concerned with rate of application of refrigeration and declares that a 300 pound block of ice, if melted in 24 hours, would provide refrigeration at the rate of 0.15 tons. Work (67) defines the expression "a ton of refrigeration," as meltage of one ton of ice in 24 hours, or removal of 288,000 B.T.U. in the same time interval. Rear (54) notes further that if in a hydrocooler, the 300 pounds of ice were melted in 3 minutes, refrigeration would be applied at the rate of 72 tons per 24 hours.

Meltage of ice is necessary to dissipate heat from several sources, according to Fisher (17). He lists these sources as heat in the vegetable, heat in packages and packaging materials, heat of plant respiration, and heat leakage into the package or load from outside atmosphere.

Cold air cooling and hydrocooling are two methods of precooling which are commonly used in packing sheds. A brief review of cold air cooling will be considered first.

Lincoln (27) states that for a thorough understanding of the construction and operation of cold-air precoolers, one should have a knowledge of engineering, controlled circulation of air, heat producing capacities of produce, and effect of relative humidity on quality of vegetables. Lincoln (27) briefly describes a typical cold air precooler. He notes that usually an iced bunker is located at one end of a storage room. Cold air is blown from the top of the bunker across stacked produce in the room. The refrigerated air returns to the bottom of the bunker for recirculation. On return, cold air passes through crates of produce and cools the commodity.

Pentzer et. al. (41) have pointed out that vegetables within a package do not cool uniformly. They noted in precooling studies that melons located at the periphery of packages cooled most rapidly. Similarly, Lloyd and Decker (28) found that outside rows of apples in baskets cooled more rapidly than innermost rows.

Several factors which determine rate of cooling are outlined by Pentzer et. al. (41). They propose that speed of cooling is dependent upon volume, velocity, and distribution of air. Another factor they consider is difference in temperature between commodities being cooled and air used for cooling. A less obvious consideration in cold air precooling is method of packing and stowing produce as it affects air circulation. Pentzer et. al. (41), Fisher (17), and Gurney and Lurie (19), stress that the properties of objects being cooled; such as size, shape, surface, heat capacity, conductivity, and metabolic activity, influence rate of cooling.

In their experiments on precooling carloads of asparagus, Pentzer et. al. (40) found that transit temperature of a precooled car averaged 45°F. the first day and 47°F. the first four days. They found by contrast that temperature in a car which was not precooled averaged 61°F. the first day and 56°F. the first four days of transit. They concluded that increased respiration rate of asparagus in the car not precooled required about one-third more ice than the precooled car.

In 1940, Pentzer et. al. (41) made studies on precooling cantaloupes. They found that thorough precooling removed enough heat from carloads of melons to reduce transit temperature of loads considerably below non-precooled or partly-precooled cars.

From studies of precooling lettuce, Platenius (48) found that rate of lowering temperature in cold air precoolers is very slow. He reported that crates remained in a cold room 30 hours before temperature of heads was lowered to 40°F. When cooled 6 hours, temperature was reduced to only 69°F. He concluded that during precooling, even though temperature was decreasing constantly, deterioration of lettuce continues. During 30 hours of precooling by cold air, 11% of the lettuce deteriorated and became unmarketable.

Hydrocooling is a second form of precooling, and in some instances is preferred to precooling with cold air. A review of some of the more pertinent literature on hydrocooling follows.

Rear (54) defines hydrocooling as refrigeration of vegetables with iced water or iced water sprays.

It has been pointed out by Pyke and Allison (51) that tap water or wash water in packing sheds has little or no refrigerating value. In refrigeration studies made with several vegetables they noted that wash water in packing houses ranged between 55° and 60°F. Truscott (64) declared that temperature of spring water was never below a temperature of 40°F. After running water from an artesian well into a wash tank, Zink (69) noted that temperature of water averaged 70°F.

A typical hydrocooler, known as an overhead drain or Stericooler, has been described by Barr and Slade (8). The machine consists of a low supply tank of large capacity, an upper header or distributor, and between these a straight wooden conveyor operating on a level plane. Crushed ice is placed in water of the lower tank where it spreads over the surface and chills water to about the temperature of melting ice. Iced water is then pumped to the distributor where it spreads out and falls in a rain-like sheet to soak and cool boxes of produce running through on the conveyor. Rear (54) and Zink (69) explained operation of a hydrocooler which is essentially the same as the one noted by Barr and Slade (8). Richards (55) designed a hydrocooler which is very similar to those reported above.

A second design of hydrocooler, the immersion cooler, is explained by Perry (43). He notes that this type of equipment is merely a tank in which moves a submerged conveyor. The tank is filled with water and loaded with crushed ice. Crates of vegetables are submerged in it and move through on a conveyor. To lower temperature of produce in this cooler below 40°F., crates must remain in the tank 10 to 15 minutes. Perry (43) points out that crates moving through the tank carry water with them which necessitates use of a pump at the exit end of the conveyor. The pumped water establishes a counterflow current to replace cold water. A serious disadvantage to hydrocooling is pointed out by Perry (44). He states that unless strict sanitation is practiced in hydrocoolers, spread of infection from diseased to healthy produce is quite possible through recirculation of water. In this discussion it is recommended to cull all diseased commodities before running produce through the cooler. In 1929, Lewis (26) described an immersion cooler which was similar in design, but more simplified.

Rear (54) advised that hydrocooling has limitations since only certain vegetables are adapted to this form of refrigeration. He noted that hydrocooling could be used successfully with celery, asparagus, peas, cauliflower, green lima beans, and carrots. Zink (69) recommends hydrocooling for celery. Pentzer et. al. (40) state that asparagus is commonly cooled with iced water. Morris (33) obtained excellent results when he hydrocooled sweet corn. According to Lewis (26), most root crops may be cooled with iced water. Mallison and Pentzer (29) reported that radishes, lettuce, and most leafy vegetables are adapted to hydrocooling. Perry (44) declared that celery, peas, and asparagus should be hydrocooled.

Pentzer et. al. (40) state that hydrocooling is a more rapid method of precooling than cold air refrigeration. They found that ten minutes of cooling in iced water lowered temperature of asparagus 22°F. In this same study, it was noted that asparagus precooled by cold air in a refrigerator car averaged 40.5°F. after 11 hours of precooling. Asparagus which was first hydrocooled for 10 minutes and then precooled by cold air reached a temperature of 40.1°F. in 6 hours, and 38.8°F. in 8 hours.

The investigations of Barr and Slade (8) substantiated the findings of Pentzer et. al. (40) in that they found hydrocooling was a much faster method of precooling than the conventional air cooling systems. These workers summarize their findings by stating that one minute of cooling in a hydrocooler accomplishes the same amount of refrigeration as one hour of normal air cooling.

In contrasting the refrigerating efficiencies of cold-air cooling and hydrocooling, Rear (54) observed that crates of asparagus were completely cooled in 10 to 12 minutes when hydrocooled, while cold-air cooling required 10 hours to bring crates to the same temperature.

Perry (43) concluded that iced water coolers require 10 to 15 minutes to reduce temperature of most vegetables satisfactorily as compared with 8 to 14 hours required for cold air coolers.

Icing Packages and Loads of Vegetables

Austin (7) remarks that deterioration may progress in vegetables at any point in the marketing channel unless commodities are properly refrigerated until they are consumed. He states that package icing and load top icing are methods of refrigeration which protect quality of vegetables from farm to market.

Mallison and Pentzer (29) call attention to the fact that icing requirements are greater during summer months than winter months. In addition, they note that during a 24-hour period, temperatures may fluctuate radically.

In studies of diurnal temperature changes, Albright (1) observed that outdoor temperature drops in a smooth curve throughout the night. Temperature is usually at a minimum just before sunrise. He found that at sunrise, temperature turns abruptly upward and rises at a rapid rate. Temperature rise slows down as day progresses, coming to an accumulative peak in the afternoon and reversing the morning curve as it drops off. An important observation made by Albright (1) was that evening cooling does not progress as rapidly as morning heating. Morris (33) noted that greatest atmospheric temperature increase occurs between 8 and 10 a.m.

Platenius (48), discussing sizes of ice, states that form of ice used in refrigerating truckloads of vegetables makes little difference in rate of cooling produce. Mallison and Pentzer (29) supported Platenius' (48) statement by noting that snow ice does not cool a load more rapidly than chunk ice. They also state that there is no difference in rate of melting between these sizes of ice.

A word of caution in use of low temperature ice is offered by Mallison and Pentzer (29). They declare that ice is frequently stored at temperatures ranging from 23° to 28°F. and if this ice should be packed in a crate of lettuce, freezing injury would result. According to Wright (68), average freezing point of lettuce is 31.2°F., which is nearly 3° higher than for most fruits and only 0.8° below freezing point of pure water. Mallison and Pentzer (29) made a study of freezing injury to lettuce and found that ice having a temperature of 25°F. or below froze this commodity and that the lower the temperature of ice, the greater was the extent of injury.

Lewis (26) maintains that small sizes of ice should be used in vegetable packages. He adds that large chunks might cut or bruise commodities when a crate cover is forced into place. Mallison and Pentzer (29) caution if there is bulge to crates which have been iced, the three bottom layers of a load should be placed on sides or damage might result from pressure of top crates. They specify that this is particularly true when large sizes of crushed ice are used in packages. In closing bulged crates of iced broccoli with hydraulic pressure, Park and Smith (37) found very little damage resulting. The amount of pressure is not specified, but these workers state that the sealed package had a 3 to 4 inch bulge.

In the first part of their report on body icing of refrigerator cars, Mallison and Pentzer (29) define several terms which are commonly used in ice refrigeration. They note that "package ice" refers to ice placed in a package with produce; "top ice" is ice placed over top of a load; "body ice" denotes any ice placed with a load, and "pigeonhole ice" is chunk ice placed in spaces left between packages of a load.

An extensive study on packing and shipping lettuce in New York was made by Platenius (48). He stated that rapid temperature drop in vegetable packages can be accomplished most efficiently by package icing. Observations showed that 4 to 6 dozen heads of lettuce are commonly packed in western type crates. Lettuce is placed in these packages with 40 to 45 pounds of crushed ice distributed between three layers of produce. He recommends that snow ice be used in packing this commodity.

Mallison and Pentzer (29) reported that western lettuce is packed with 30 to 35 pounds of ice in a crate holding 48 heads. Crushed ice is placed between the three layers of lettuce with a few pounds on the top layer. These workers noted that middle layer of heads was 17°F. cooler than bottom layer after 24 hours, and attribute this temperature difference to the fact that middle layer had ice both above and below it while the bottom layer was iced only on top of the heads.

A unique method of packing ice in lettuce crates is described by Spangler (62). He notes that waxed or parchment paper is folded in such a manner that ice is contained in an improvised envelope between layers of heads. Spangler (62) stresses that the advantage of this method of package icing is that leaves do not become ice bruised and midribs of outer leaves do not discolor.

In 1921 Ridley (56) reported that package icing of spinach may be used to advantage in long-distance shipments. He explains that temperature of spinach below ice was uniformly between 35° and 40°F. Spinach above ice in the package was at 61°F. when loaded and was not reduced below 42°F. during several days of transit. Temperature was largely equalized when part of the ice was placed on top of the package. He noted that the usual method of icing spinach was that of placing approximately 14 pounds of ice in a single layer at the center of a bushel basket. A more recent study on icing spinach has been made by Park and Smith (37). They state that ice is usually added to a package of spinach after the basket is one-half to two-thirds full. The crates are topped with 5 to 10 pounds of crushed ice.

Lewis (26) describes a common method of packing root crops in western type crates. He reports that 4 to 6 dozen bunches of beets or carrots, or 3 to 5 dozen bunches of turnips are packed in crates with ice either entirely in the center of a crate or in 2 or 3 layers.

Studies on icing sweet corn are reported by Morris (33). This investigator stresses that sweet corn should be packed and shipped in direct contact with package ice. He notes that 35 pounds of crushed ice in a crate of six dozen ears lowered transit temperature to 40°F. In a later publication Morris (34) stated that three or four layers of corn are packed in a crate and each layer is separated by a layer of crushed ice. Also working with sweet corn, Slater and Hardenburg (60) recommended that 10 to 12 pounds of crushed ice be placed in a Bruce crate. It will be noted that this is 25 pounds less than the amount recommended by Morris (33).

Wet-strength paper liners placed in iced packages of vegetables are used extensively. Holbrook (23) defines wet-strength material as paper which retains a substantial degree of its original strength properties after immersion in water. The statement was made by Comin (14) that the object of enclosing vegetables with a paper liner is to reduce transpiration. He explains further that closing a package aids in maintaining a high relative humidity in the atmosphere directly surrounding vegetables. From his data, Comin (14) concluded that it is possible to store vegetables in locations where the atmosphere is dry provided produce is packed in containers which prevent moisture losses.

Nylund (36) found essentially the same advantage in using package liners. With carrots, he found that roots stored in unlined baskets for 137 days lost 32% of their original weight. On the other hand, roots stored in baskets protected with paper liners lost less than 10% weight in the same time period.

Lewis (26) states that oiled or waxed paper may be used to line crates provided the paper is of wet-strength grade.

In his extensive work on paper wrappers, Brown (10) noted that celery wrapped with parchment paper lost much less moisture than celery not wrapped. When packages of lettuce were placed in a low relative humidity chamber weight loss was high in check and whalehide lots, but self-sealing waxed paper gave excellent protection.

Use of paper liners is also recommended by Carolus (13), Park and Smith (37), Lloyd and Decker (28), and Platenius (48).

Work (66) summarizes advantages of paper liners in iced crates by concluding that they keep the product clean and protected against disease infection; they retard wilt, prevent mechanical injury, protect produce against unfavorable temperature, and are attractive. Other advantages of paper liners are offered by Spangler (62). He notes that paper liners prevent ice from sliding out of crates, and aid in holding refrigeration in packages.

According to Mallison and Pentzer (29), top icing loads of packed vegetables is common. They assert that crushed ice is blown over the top of a load. These workers found that top icing kept package temperatures uniformly low during transit with the result that very little spoilage resulted. Rear (54) points out that top icing a load does not cool it as rapidly as precooling with iced water. Top icing for long-distance shipments is recommended by Park and Smith (37). Spangler (62) states that most lettuce shippers use snow or crushed ice in topping a load, but that some use block ice. He cautions that block ice often causes damage if it slides over tops of crates, and for this reason, recommends snow or crushed ice. Platenius (48) also recommends snow ice for topping loads of lettuce. He reports that this fine grade of ice may be blown into spaces between crates and thus do a more complete job of refrigerating loads. Platenius (48) also discourages use of block ice because of danger of injury to crates and produce. In this study, he found transit temperature of a top-iced load to be 56°F. in the top layer of crates, 63°F. in the center layer, and 66°F. in the bottom tier. He concluded that a better job of refrigeration would be accomplished if snow ice were distributed in several layers throughout the load rather than all on the top of the load.

From investigations on refrigerating cantaloupes, Fisher (18) concluded that top-icing refrigerator cars resulted in lower transit temperatures than conventional precooling with bunker ice. His data also exhibits the manner in which a temperature gradient is established through a load. He states that temperature of top layer of crates in a top-iced car averaged 43° to 38°F. while the corresponding layer in bunker-iced car was 54° to 48°F. Middle layer of crates in the top-iced car averaged 38° to 36°F. and the same layer in bunker-iced car was 55° to 42°F. Bottom tier of crates in top-iced car averaged 36° to 33°F. and the corresponding layer in the bunker-iced car was 45° to 37°F.

Campbell (11) and Ridley (56) also recommend top-icing of vegetable loads.

Ice Refrigeration on Store Produce Counters

In 1946, Hauck (21) conducted a survey to determine shelf life of vegetables on retail store counters. He observed that out of each 100 pounds of various vegetables received, 36.1 pounds of beets, 32.3 pounds of cauliflower, 20.4 pounds of lettuce, and 14.8 pounds of broccoli spoiled and were unfit for sale. From a survey conducted the following year, Stokes (63) concluded that 8.5% of all vegetable retail value was lost as a result of spoilage. Stokes (63) recommended that open faced vegetable counters be used, and that the temperature of the displays be maintained at 40°F. As a result of this study it was also emphasized that produce be stored in refrigerated boxes until placed on display.

It has been stressed by Brasher et. al. (9) that many products are sold by weight and that refrigerating vegetables with snow ice prevents shrinkage losses. With six different vegetables used in this study, appearance and palatability of all vegetables decreased markedly when held at room temperature.

Carolus (13) found that movement of dry refrigerated air over vegetables on a display counter resulted in considerable dehydration of the produce.

In her vegetable retail studies, Patton (39) found that leaf vegetables lost moisture more rapidly than more compact vegetables such as asparagus and peas. Vegetable waste in a display tray which was not iced amounted to 22 pounds in a week, while a corresponding iced tray yielded only 7 pounds of waste. Patton (39) concluded that use of crushed ice on vegetable display reduced spoilage materially.

In making recommendations for retail handling of vegetables Knott and Platenius (25) suggested that spinach be displayed on a retail counter with crushed ice.

Slater and Hardenburg (60) found that displaying sweet corn on crushed ice lowered temperature of ears 15° to $18^{\circ}F$. They also observed that crushed ice aided in maintaining fresh green color of husks.

An article published in the September 1946 issue of Super Market Merchandising (3) pointed out that counter icing eliminates necessity of storing produce in a refrigerator at night and over weekends. To place a layer of crushed ice over the display and cover with an insulated rubber mat was recommended in this paper. Also appearing in this article are directions for icing counter displays. It is noted that a 2 to 4 inch layer of ice is placed on the bottom of a counter. A "ribbon like" display is built by arranging successive layers of produce with thin layers of ice until display is at desired height. It was noted that a bed of 75 pounds crushed ice is used in a six foot section of counter. The vegetables are garnished with 25 to 75 pounds of crushed ice.

Pillar (45) states that use of ice on vegetables suggests freshness and hence has considerable advertising value.

MATERIALS AND METHODS

Packages of vegetables were iced in packing sheds at various farms in Massachusetts. Crates or boxes were then followed either to a wholesale market or directly to a retail store. Crate temperatures were recorded hourly, and deterioration of the produce was noted.

Vegetables Used

In selecting vegetables for experiments, care was taken to include commodities which are representative of those commonly marketed in Massachusetts. Typical root, stem, leaf, and seed crops were selected. Vegetables were chosen which represent a wide range of heat evolution capacities. The following five vegetables were used in these experiments (heat evolved per ton of vegetable at a storage temperature of 60°F. in a 24-hour period is listed with each product): carrots (8,080 B.T.U.), celery (13,520 B.T.U.), lettuce (45,980 B.T.U.), spinach (36,920 B.T.U.), sweet corn (38,410 B.T.U.) (57).

Ice Grades

Crushed ice is known variously as sized, processed, shaved, and bagged ice. To manufacture this ice, bar or cake ice is placed in a grinder which is equipped with hook teeth. From the grinder, pulverized ice is dumped into a large rotating wire drum. The crushed ice then drops through the wire into individual bins thereby separating the grades of processed or sized ice.

The ice industry has standardized crushed ice into five grades, according to the size of wire mesh through which ice will pass (15) (61). The following list names these grades with the designation used in this paper. The alternate term which is sometimes applied and the size of mesh through which ice of a given grade will pass is also listed.

Grade	Designation Used in this Paper	Alternate Term	Size of Mesh
Number one ice	#1	snow ice	3/16"
Number two ice	#2	fine ice	1"
Number three ice	#3	medium ice	1-1/2"
Number four ice	#4	coarse ice	2"
Run-of-the-line ice	R. of L.	crusher ice	comes directly from grinder without sizing. Includes grades #1 through #4.

Amounts of Ice Used in Containers

Amounts of ice used for the several packs varied with size of the container. In approaching the problem of the optimum amount of ice to use in a given type of package, the quantity that the grower ordinarily used was regarded as a reference point, and in some experiments, additional amounts were added.

Another variable was placement of ice in the package. Some vegetables were packed in containers with ice divided in three layers, some with two layers, and some with ice placement on the top of the package only. To obtain further combinations, different grades of ice were used in packages. In two sweet corn experiments, a sample package was soaked with tap water in an effort to determine cooling effect of water. In many experiments, a package was lined with wet-strength paper before it was packed and iced. Becuase packing and icing varied in so many respects, this subject is noted more in detail for specific experiments under PRESENTATION AND DISCUSSION OF DATA.

Thermometers and Use in Packages of Vegetables

Several workers, (22), (28), (29), (40), (41), have used electrical resistance thermometers for recording package temperatures. All of these studies have been conducted in refrigerator cars on long-distance shipments.

Glass or metal thermometers have not been used very extensively for obtaining package temperatures. In his vegetable cold storage experiments, Platenius (47) placed thermometers in the center of vegetable crates and took readings hourly.

Temperatures were taken with Weston all-metal Fahrenheit thermometers. This type of thermometer has a circular dial which is 1-3/8 inches in diameter. Temperature is recorded on the glass-faced dial. The large dial was found to facilitate reading of temperatures, particularly when lighting was poor. The thermometer is equipped with an eight inch stainless steel stem. Only the last two inches of the stem are sensitive to temperature. Temperature recording is guaranteed to be accurate to one-half of 1% over the total scale (0° to 180°F.). Thermometers were checked weekly in ice packs to determine their accuracy.

Thermometers were placed in the center of a package with the stem end in the container, and face of the dial against the outside of the crate. Because of the localized sensitivity of the stem, temperatures were obtained six inches to eight inches inside the pack. The gradient temperature from six inches inside the crate to the crate wall did not affect the reading.

Temperature Recording

Special care was used in placing thermometers in crates of vegetables. In check crates and crates which were top-iced only, thermometers were placed in the center of the package. In crates which had ice distributed in the center and on the top, thermometers were placed mid-way between the center layer of ice and the bottom of the container. In paper lined crates, a small hole was punched in the paper, and the thermometer stem was inserted through the opening.

After containers had been packed and iced, package temperatures were recorded at 15-minute intervals during the first hour. This procedure was followed because preliminary experimentation showed that the most radical temperature changes took place during the first hour after packages had been iced. Thus temperatures are recorded in Appendix tables and plotted on graph figures at 15, 30, 45, and 60 minutes after packing. After the first hour, temperatures were recorded hourly.

Temperature Gradients in Stacks of Packages

Thermometers were placed in top, center, and bottom packages in stacks of produce which were loaded on trucks. Placement of thermometers in individual crates was the same as that outlined previously.

Precooling Lettuce with Iced Water

Precooling with iced water will be referred to in this discussion as hydrocooling. Studies were conducted on two kinds of hydrocoolers.

The overhead-drain cooler (Fig. 1) is a machine which is equipped with a low supply tank and an upper header or distributor. The distributor is perforated with small holes. A conveyor operates on a level plane between the supply tank and the distributor. Crushed ice is placed in water in the low tank where it spreads over the surface and cools water to about the temperature of melting ice. The iced water is then pumped to the overhead distributor where it spreads out and falls through 3/16 inch holes. The water falls down in a rain-like sheet soaking and cooling the crates of vegetables which are moving through on the conveyor.

The immersion hydrocooler (Fig. 2) is much more simple in design. This equipment consists of a tank in which moves a submerged conveyor. The tank is filled with water and crushed ice. Crates of lettuce are clamped to the submerged conveyor and move through the iced water thereby washing and cooling simultaneously.

Experimental crates remained in both hydrocoolers three minutes. Temperatures were taken with Weston all-metal Fahrenheit thermometers by pushing the stem into the center of heads. In each experiment, temperatures were taken in twenty lettuce heads from the top layer, and twenty heads from the bottom layer.

<u>Figures and Tables</u>

Data is presented with accompanying graph figures and diagram figures. Figures are designated by Arabic numerals. Tables appearing in PRESENTATION AND DISCUSSION OF DATA are designated by Roman numerals. Appendix tables are differentiated by capital letters.

Figure 1. Diagrammatic Sketch of an Overhead-Drain Hydrocooler

-- After Richards (55) --

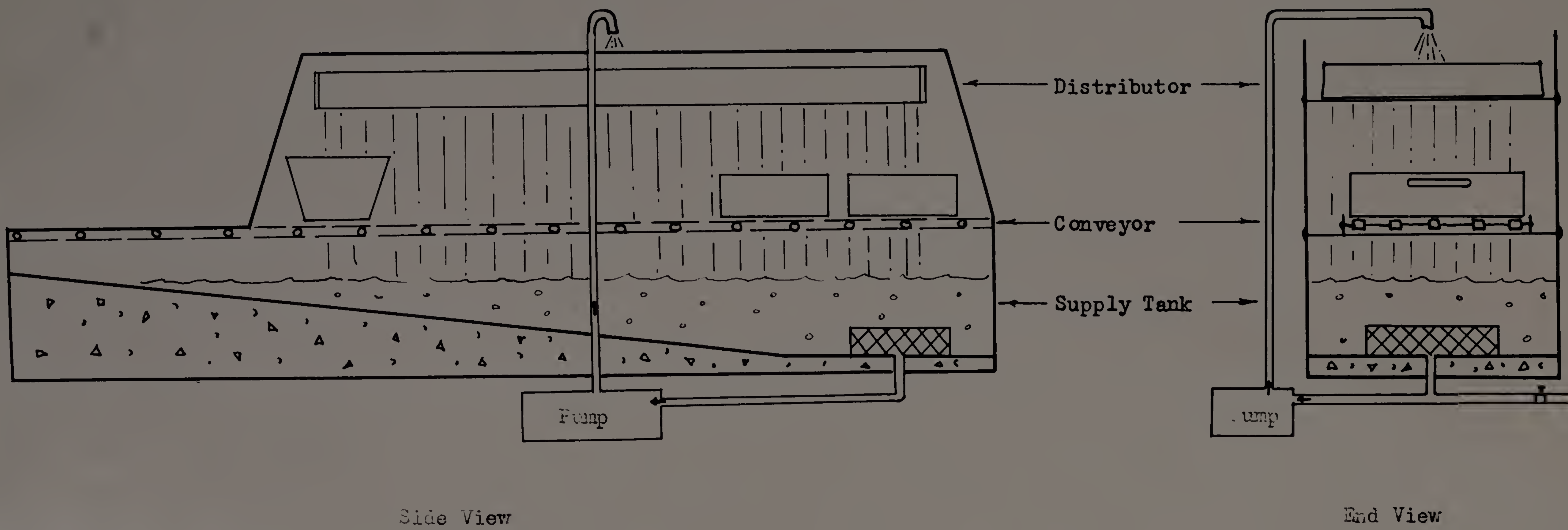
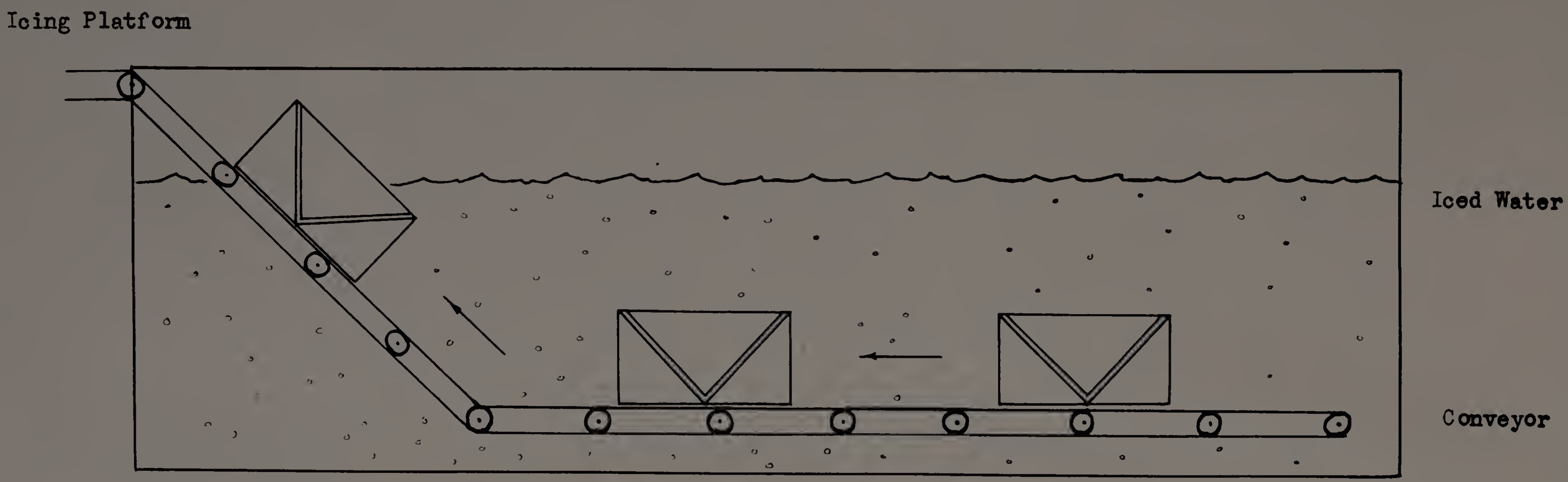


Figure 2 Diagrammatic Sketch of an Immersion Hydrocooler



PRESENTATION AND DISCUSSION OF DATA

Package Icing Experiments

Experiments are reported in which vegetable packages were iced. Temperature and deterioration history of produce from the grower to a wholesale market and to a retail store is noted on these containers. In some instances, the procedure of marketing is directly from grower to retailer, omitting the wholesale market phase. Certain other experiments follow packages from the grower to the wholesale market, and omit the retail phase.

Size of ice designations used in this discussion are explained under MATERIALS AND METHODS.

It was found throughout the experiments that small sizes of ice lowered temperature most rapidly. Large sizes of ice dropped package temperature more slowly than the small sizes, but maintained the lowered temperature for a longer period of time than did the small sizes. To make discussion brief, this relationship is referred to as a reverse temperature trend.

Package Icing Carrots - Experiment I

Crates of bunched carrots were iced August 25, 1948 in the packing shed of Vernon A. Doty, West Springfield, Massachusetts. The following morning, packages were hauled to the Springfield Farmer's Market. At 9:00 a.m. crates which were not sold were returned to the packing shed. This experiment was conducted over a period of 25 hours.

Method of Packing and Icing

Carrots were harvested between 9:00 a.m. and 12:00 a.m. Roots were washed, bunched, packed, and iced. Three dozen bunches of carrots were packed in each Bruce crate.

Five methods of packaging were used in this experiment:

Crate No. 1. Grower's method #1 ice (7 pounds on bottom dozen of bunches; 7 pounds on center dozen; 7 pounds on top dozen).

Crate No. 2. #2 ice (Same placement as No. 1).

Crate No. 3. #3 ice (Same placement as No. 1).

Crate No. 4. #4 ice (Same placement as No. 1).

Crate No. 5. Check - no ice.

Market Temperature History of Crates

Carrots were packed and iced at 3:00 p.m. At 5:00 a.m. the following morning the load arrived at market and temperatures were recorded hourly until 9:00 a.m. At this hour, crates were hauled back to the packing shed, and at 4:00 p.m. temperatures were again taken.

Small sizes of ice lowered temperature most rapidly, but did not maintain the low temperature as effectively as the large sizes. Thus it will be noted that a reverse temperature trend is operative (Fig. 3).

The average atmospheric temperature, 83.6°F., (Table I) was the highest recorded in the two seasons that this project was conducted. It will be noted in Table I that average temperatures in crates with the various grades of ice were irregular and did not conform with the trends found in experiments with other crops. These variable averages may have resulted from the abnormally high atmospheric temperature which prevailed during the experiment.

It is noteworthy that temperature of the check crate remained remarkably uniform and for the most part, below the atmospheric temperature. This indicates that carrots do not evolve appreciable quantities of heat. This observation is substantiated by the findings of Rose et. al. (57). These workers noted that carrots evolved only 8,030 B.T.U. per ton in 24 hours when stored at a temperature of 60°F. Spinach generated four times this amount of heat while lettuce liberated over five times the amount of heat evolved by carrots. From this it would seem that a unit of weight of carrots would require less package ice than an equal weight of spinach or lettuce.

Under conditions of extremely high atmospheric temperatures, ice refrigerates vegetable packages for only a short period of time. It will be noted that the lowest package temperature at the twenty-fifth hour was 68°F. (Fig. 3).

The #1 ice and #2 ice were completely melted in 14 hours. After 14 hours, the top layer of grades #3 and

#4 were completely melted, but ice was still present in the center and bottom layers. Ice was completely melted from all packages at the twenty-five hour reading. Thus it will be noted that the larger sizes of ice had the greatest lasting value.

Carrots - Experiment II

Carrots were iced August 26, 1948 in the same packing shed that Experiment I was conducted at. The following morning, crates went to the same market as packages in Experiment I.

The same five methods of packing and icing were used as described in Experiment I.

Market Temperature History of Crates

Carrots were packed and iced at 10:00 a.m. At 4:00 a.m. the following morning crate temperatures were taken in the wholesale market.

Table I
Average Temperature of Carrot Crates

Treatment	Experiment I	Experiment II
#1 ice	64.3°F.	53.3°F.
#2 ice	67.0°F.	55.2°F.
#3 ice	60.5°F.	54.2°F.
#4 ice	56.8°F.	60.3°F.
Check-No Ice	80.0°F.	79.2°F.
Atmospheric Temperature	83.6°F.	81.3°F.

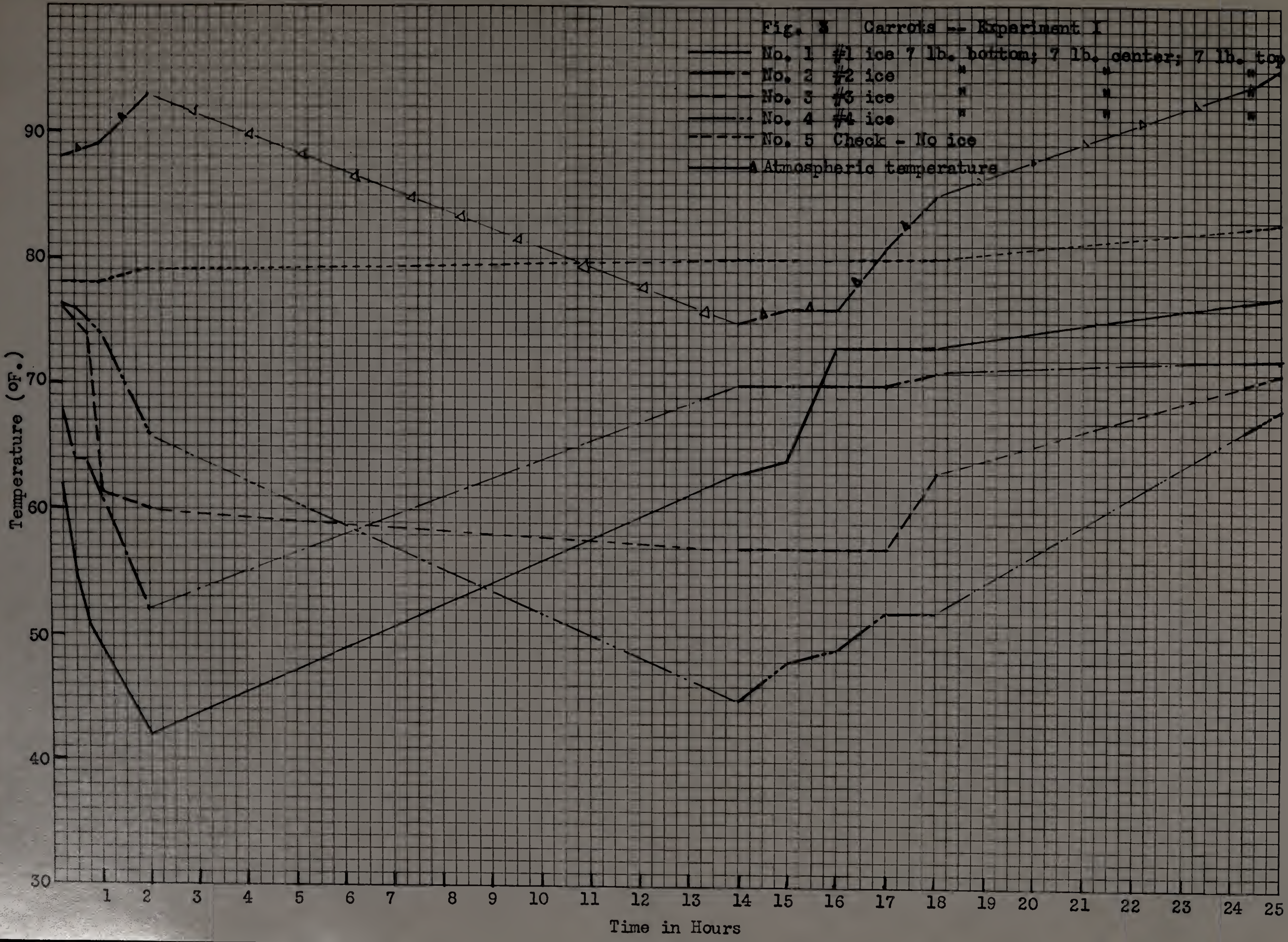


Fig. 8 Carrots -- Experiment I

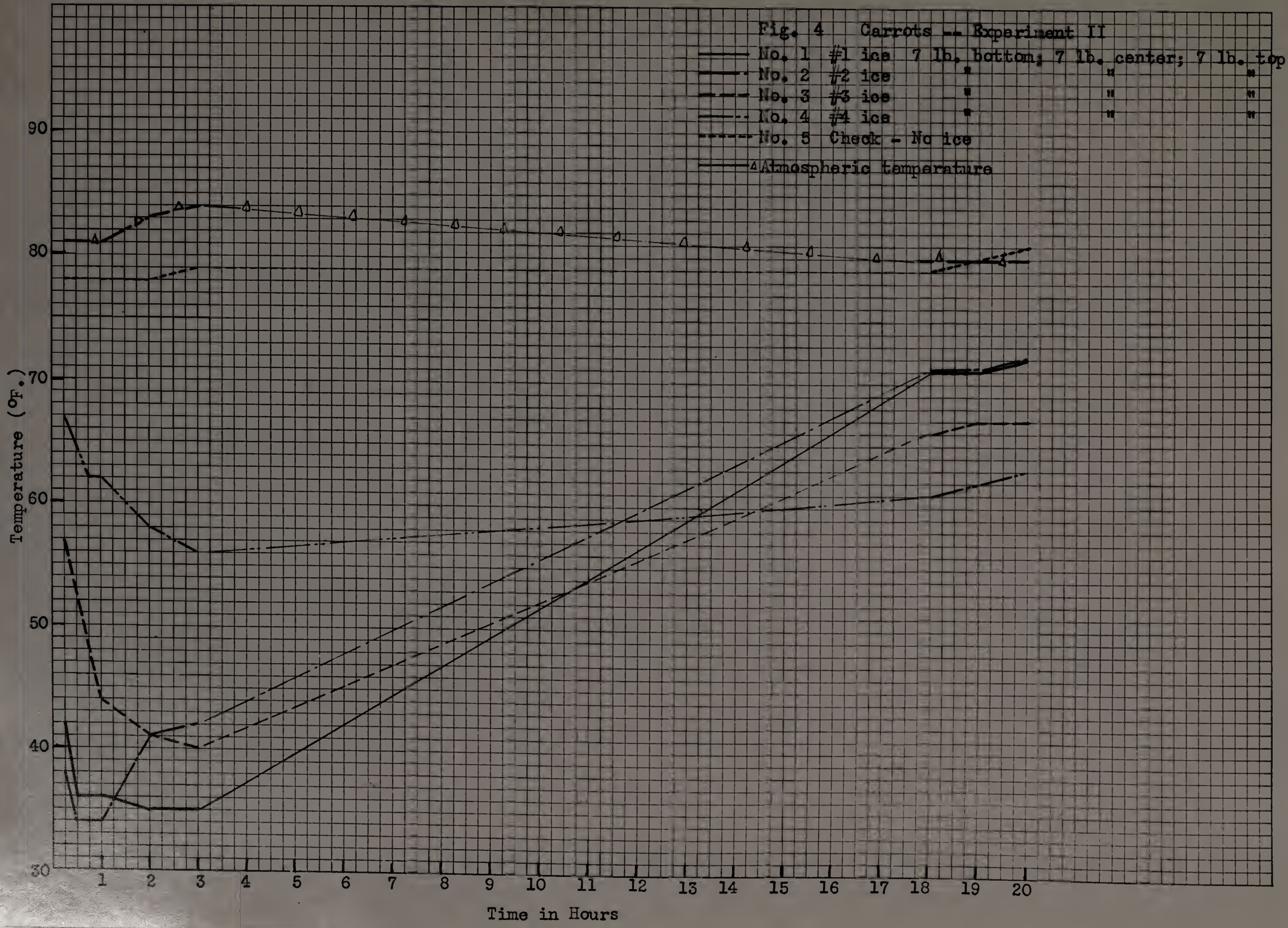


Fig. 4 Carrots -- Experiment II
No. 1 #1 ice 7 lb. bottom; 7 lb. center; 7 lb. top
No. 2 #2 ice " " "
No. 3 #3 ice " " "
No. 4 #4 ice " " "
No. 5 Check - No ice
Atmospheric temperature
Temperature (°F.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Time in Hours

The reverse temperature trend is apparent in this experiment (Fig. 4). Similar temperature relationships are noted as were found in Experiment I.

Ice was completely melted in all packages at the eighteenth-hour reading.

Package Icing Celery - Experiment I

Packages of celery were iced August 12, 1947 at the Richardson and Whitmore Farm in Sunderland, Massachusetts. The lot of experimental crates was followed to the residence of the trucker, Mr. Henry Stoughton, South Amherst, Massachusetts. The celery remained there overnight in a closed army reefer-type truck. On August 13, this celery was observed in transit to Springfield, Massachusetts. It remained at the wholesale selling lot for four hours and one hour in a retail store. This experiment was run over a period of 21 hours.

Method of Packing and Icing

Celery was harvested between 7:00 a.m. and 9:00 a.m. It was hauled to the packing house in western-type crates, and stacked outside in the shade. Celery was placed on a circular wire platform which revolved under two streams of water. Wash water averaged 68°F. (average of ten readings).

After being washed, celery was wrapped and packed in tomato lug boxes, one dozen bunches per pack. Lug boxes measured 14" x 18" x 7".

The grower's method of icing was to place four bunches of celery in the bottom of a box, with approximately 3 pounds of R. of L. ice placed over this layer. Two more layers of celery were placed on top, and 3 pounds of R. of L. ice placed over this. A piece of wet-strength paper was placed over the top layer of ice, and a wooden slat was nailed across the top of the box.

Eight methods of packaging were used in the experimental run:

Experiment I-A -- Six pounds ice per box.

Box No. 1. Grower's method - R. of L. ice (3 pounds on top of package and 3 pounds in center).

Box No. 2. #2 ice (3 pounds in each of 2 layers).

Box No. 3. #3 ice (3 pounds in each of 2 layers).

Box No. 4. #4 ice (3 pounds in each of 2 layers).

Experiment I-B -- Ten pounds ice per box.

Box No. 1. R. of L. ice (5 pounds on top of package and 5 pounds in center).

Box No. 2. #2 ice (5 pounds in each of 2 layers).

Box No. 3. #3 ice (5 pounds in each of 2 layers).

Box No. 4. #4 ice (5 pounds in each of 2 layers).

Market Temperature History of Celery

Celery was packed at 11:00 a.m. At 7:00 p.m., 8 hours after packing, boxes were stacked on the truck. Temperatures that were recorded from 7:00 p.m. to 5:00 a.m. the following morning were taken on the truck. At 5:00 a.m., boxes were unloaded and stacked in an open-air market lot. Boxes were taken to a retail store at 7:00 a.m., and the 8:00 a.m. reading was made at this store. All temperatures were taken at center of the crate, between the top and middle layers of bunches.

Reversal of temperature trends was found at the seventeenth-hour reading in both Experiment I-A and Experiment I-B (Figs. 5 and 6). Small sizes of ice lowered temperature most rapidly during the first hours of the experiments, but temperatures were found to rise sharply toward the later hours. On the other hand, initialy, the large sizes of ice lowered temperature slowly, but as the hours passed, larger sizes maintained a lower temperature than small sizes.

It was observed that when #2 ice was used, the average package temperature was 53.9°F. in Experiment I-A and 49.3°F. in Experiment I-B (Table II). With the R. of L. ice, average package temperature was 51.4°F. in Experiment I-A and 47.7°F. in Experiment I-B. Average box temperature of grade #4 was 56.5°F. in Experiment I-A and 53.1°F. in Experiment I-B.

In reviewing average temperature for different grades, a definite relationship seems operative between size of ice and level to which temperature is lowered. In Experiment I-A, average temperature was found to vary from 51.4°F. - temperature attained with the smallest size of ice, up to 56.5°F., which was the average temperature of the package with the largest size of ice. Similarly, in Experiment I-B, average temperature varied from 47.7°F. in packages with the smallest size of ice up to 53.1°F. in boxes with the largest size of ice.

Temperatures were consistently lower in Experiment I-B (Table II) which had 10 pounds of ice, than temperature in Experiment I-A with 6 pounds of ice per package.

Package ice in Experiment I-A lasted six hours in most of the boxes. In Experiment I-B, the ice was completely melted in eleven hours.

Deterioration of Celery in Marketing

Color did not change, and no spoilage was observed. Several crates which had been packed August 10 were still on the truck. This celery had blanched somewhat, and the foliar portion of petioles had curled considerably. Top layer of celery in packages on the bottom of the load (stacked 6 boxes deep) showed some rust-colored pitting on the petioles. Pitting was found to result from pressure exerted by top packages which pushed pieces of ice into tender stalks.

Celery - Experiment II

Packages of celery were iced August 19, 1948 at Richardson and Whitmore's farm. Work was done in the same packing shed in which 1947 experiments were started. This lot was hauled to the Springfield Farmer's Market in the same truck used for experiments the previous year. It was not possible to follow this lot to a retail store. However, box B-2 was observed at Leonard's Market in North Wilbraham, Massachusetts.

The grower's method of packing was the same as in 1947, except that #1 ice was used in the place of R. of L. The other methods of packaging and quantities used were the same as employed in Experiment I.

Market Temperature and Deterioration History of Celery

Celery was packed at 2:00 p.m. At 6:00 p.m., boxes were stacked on the truck. From the fourth to the twelfth hour, temperature was not recorded. At the twelfth hour, 2:00 a.m., crate temperatures were taken in the truck. A 3:00 a.m. reading was not taken because the load was being hauled to market. From 4:00 a.m. to 10:00 a.m., package temperatures were recorded hourly in the open-air market at Springfield, Massachusetts.

It will be noted (Figs. 7 and 8) that temperatures in this run were consistently lower than the 1947 run. Lower package temperatures were the result of unseasonably low atmospheric temperatures since identical amounts of ice were employed as in 1947.

Temperature in #1 ice packages in both lots dropped to 33°F. in 15 minutes and the temperature remained at this level for the first four hours. Small sizes of ice lowered temperature most rapidly, but did not maintain refrigeration as long as large sizes. Furthermore, small sizes dropped temperature to a lower level than large sizes. This same observation was made in Experiment I. Temperature in packages of Lot B were consistently lower than temperature in corresponding iced packages of Lot A (Table II). This would be expected because Lot B was packed with 10 pounds of ice per box while Lot A had only 6 pounds.

A review of average temperature for different grades during the 20 hours that temperature was recorded fails to show a relationship between size of ice and level to which temperature was lowered (Table II). The spread between extremes of average temperature is only 0.6°F. in Lot A, and 2.1°F. in Lot B. This small spread may be attributed to the low atmospheric temperatures which prevailed during the experiment. Higher atmospheric temperatures were found in Experiment I, and the spread between extremes of average temperature was 5.1°F. in Lot A and 5.4°F. in Lot B.

Package ice in Lot A lasted twelve hours in all the boxes. Ice in Lot B lasted seventeen hours in most of the boxes.

Celery did not show visible signs of deterioration up to 20 hours after icing. However, box B-2 was followed to a retail market where a portion of produce was placed on an unrefrigerated counter. In two hours, this celery showed wilt, and after eight hours it was unmarketable.

Table II
Average Temperature of Celery Packages as Related to Size of Ice

Experiment I

Size of ice	Lot A - (6 pounds ice per box). Average temp. based on hourly readings for 15 hours.	Lot B - (10 pounds ice per box). Average temp. based on hourly readings for 15 hours.
R. of L.	51.4°F.	47.7°F.
#2	53.9°F.	49.3°F.
#3	55.3°F.	52.6°F.
#4	56.5°F.	53.1°F.

Experiment II

Size of ice	Lot A - (6 pounds ice per box). Average temp. based on hourly readings for 13 hours.	Lot B - (10 pounds ice per box). Average temp. based on hourly readings for 13 hours.
#1	46.5°F.	45.3°F.
#2	45.9°F.	43.2°F.
#3	46.1°F.	43.2°F.
#4	46.5°F.	43.8°F.

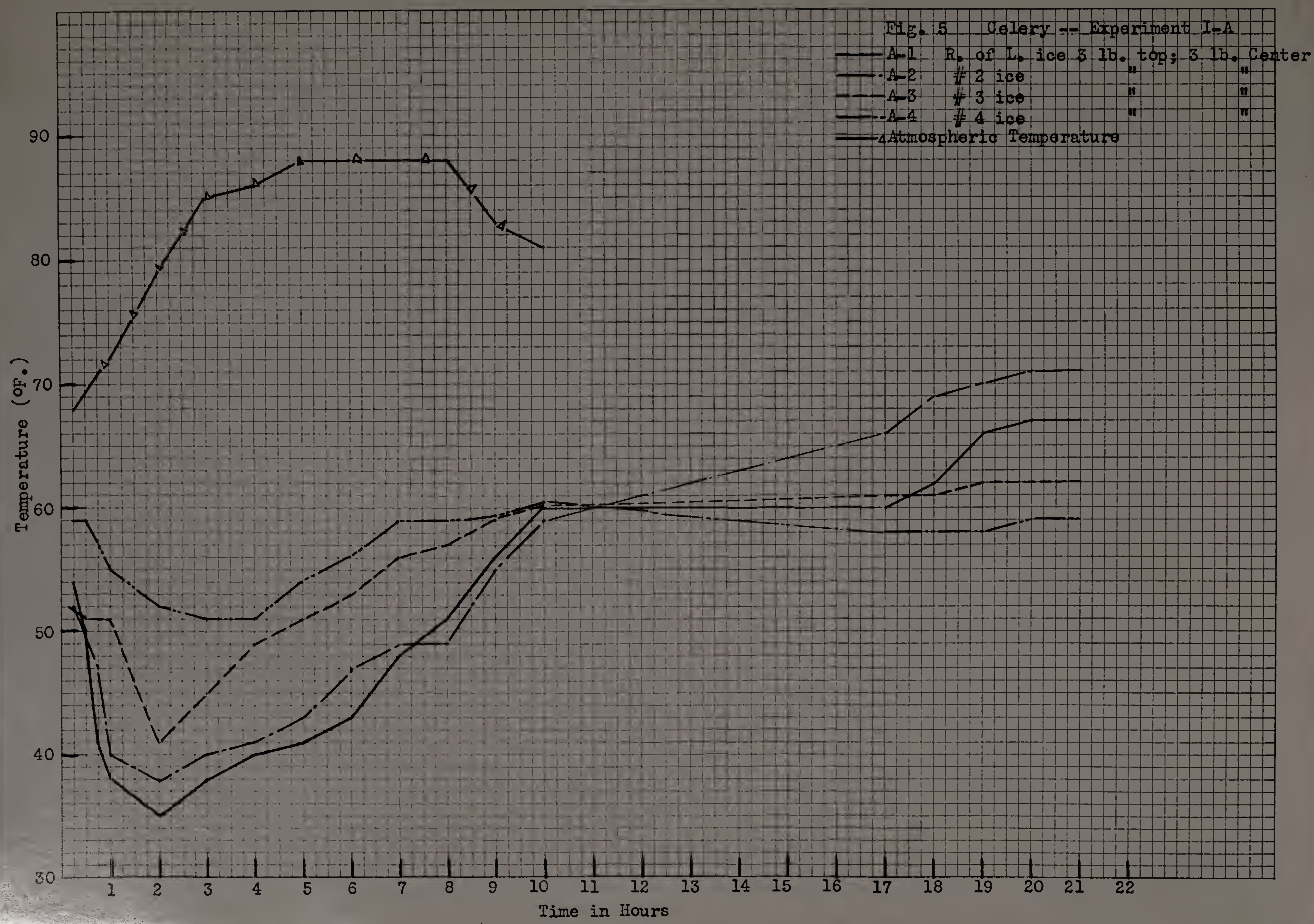


Fig. 5 Celery -- Experiment I-A
A-1 R. of L. ice 3 lb. top; 3 lb. Center
A-2 # 2 ice " "
A-3 # 3 ice " "
A-4 # 4 ice " "
Atmospheric Temperature
Temperature (oF.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Time in Hours

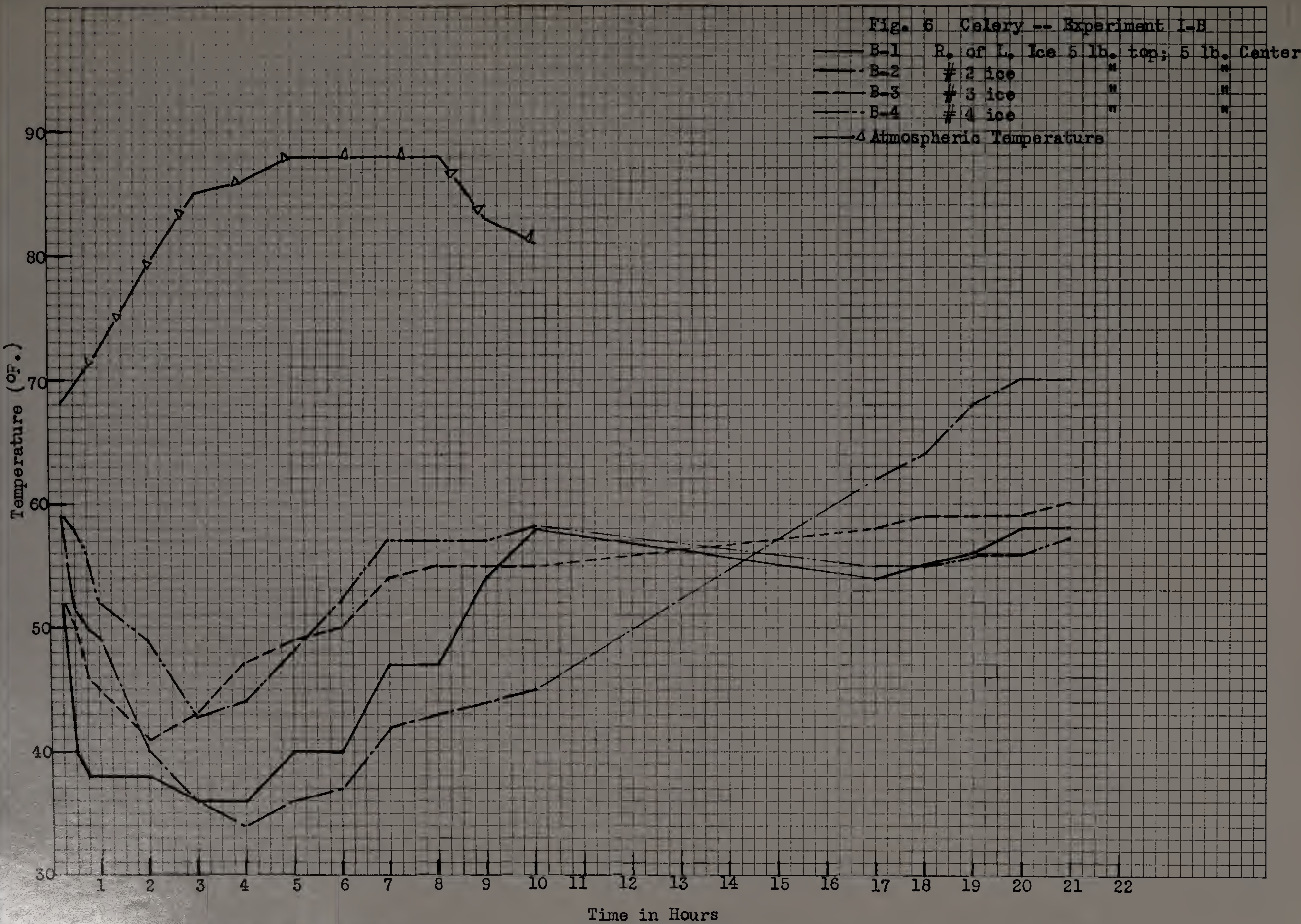


Fig. 6 Celery -- Experiment I-B
B-1 R. of L. Ice 5 lb. top; 5 lb. Center
B-2 # 2 ice " "
B-3 # 3 ice " "
B-4 # 4 ice " "
Atmospheric Temperature
Temperature (°F.)
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Time in Hours

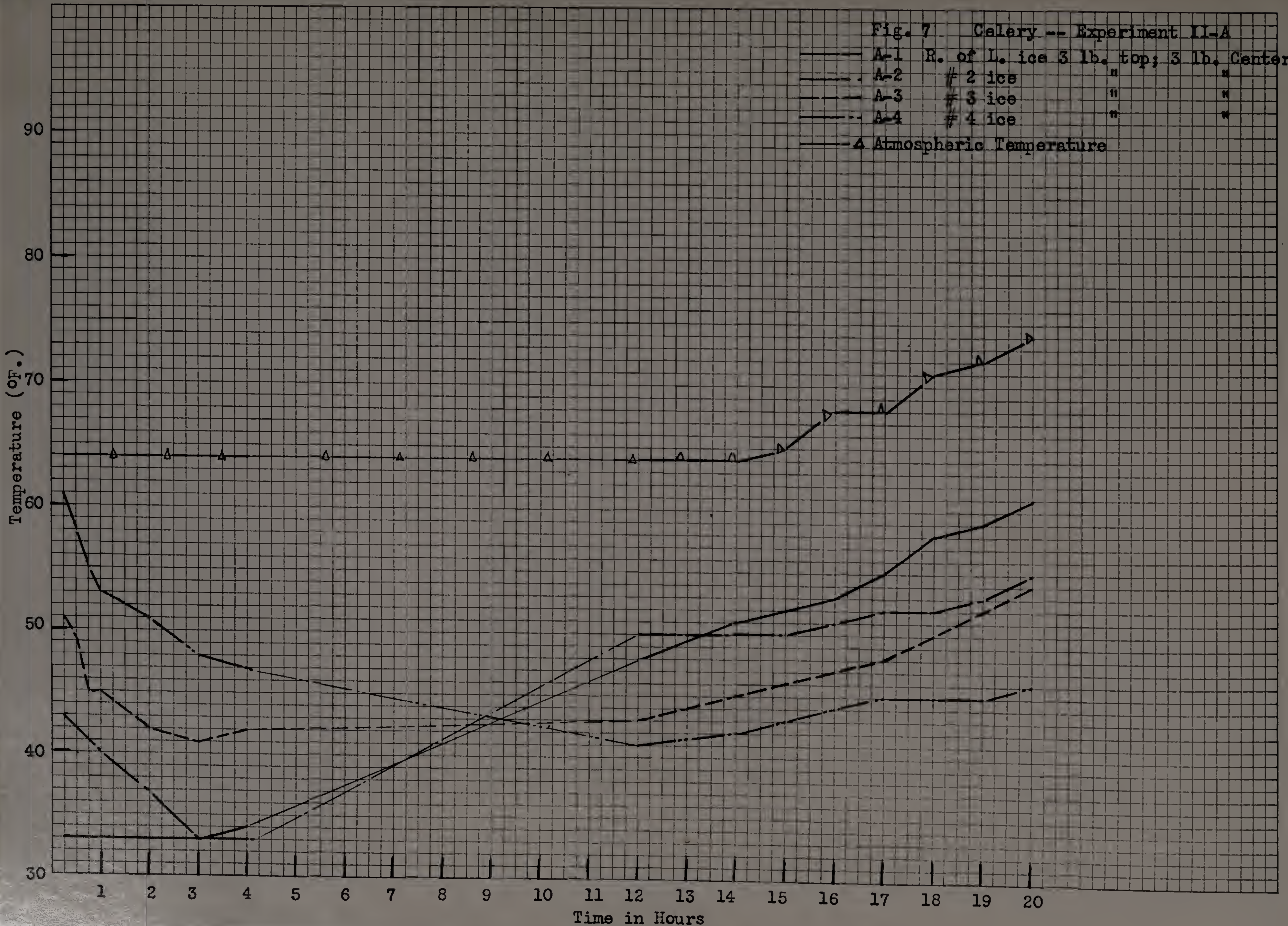


Fig. 7 Celery -- Experiment II-A
A-1 R. of L. ice 3 lb. top; 3 lb. Center
A-2 # 2 ice " "
A-3 # 3 ice " "
A-4 # 4 ice " "
Atmospheric Temperature
Temperature (°F.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Time in Hours

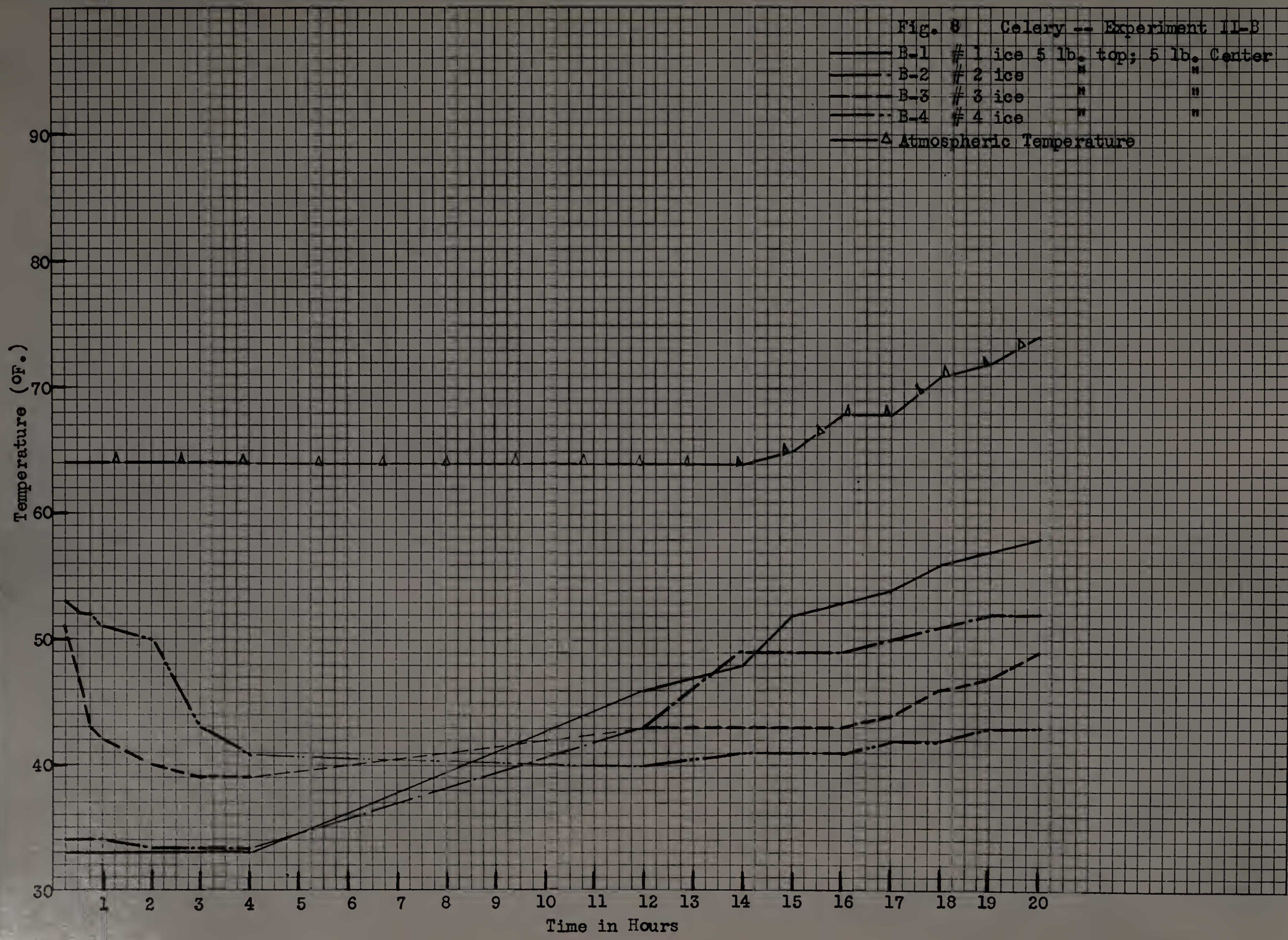


Fig. 8 Celery -- Experiment II-B
B-1 # 1 ice 5 lb. top; 5 lb. Center
B-2 # 2 ice " "
B-3 # 3 ice " "
B-4 # 4 ice " "
Atmospheric Temperature
Temperature (oF.)
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Time in Hours

Package Icing Lettuce

Six experiments were conducted in the summer of 1948. All experiments were conducted on the same farm and in the same wholesale market and retail store. The grades of ice used in packaging were #1 and R. of L.

Experiment I

Boxes of lettuce were iced July 26, 1948 in the packing shed of Herbert A. Holmes, West Bridgewater, Massachusetts. This experiment was conducted over a period of eighteen hours.

Methods of Packing and Icing

Lettuce was harvested between 9:00 a.m. and 12:00 a.m. It was packed in the field, 12 heads per box. Boxes measured 18½" x 11" x 14½". Boxes were brought in from the field and submerged in a tank of water. The average temperature of the water was 71.3°F. (20 readings).

Five methods of packaging were used:

Box No. 1. #1 ice (20 pounds placed on top of package only).

Box No. 2. #1 ice (10 pounds placed on top; 10 pounds in center).

Box No. 3. R. of L. ice (20 pounds placed on top of package only).

Box No. 4. R. of L. ice (10 pounds placed on top; 10 pounds placed in center. Package lined with paper).

Box No. 5. Check - no ice.

Temperature History of Boxes and Deterioration of Lettuce

Lettuce was iced at 3:00 p.m. At 6:00 a.m. the following morning, temperature of crates was taken in the Brockton Farmer's Produce Market. At 9:00 a.m., box temperatures were recorded at an A. & P. store on Main Street, Brockton, Massachusetts.

It will be noted in Figure 9 that the only box which maintained a low temperature to the fifteenth hour, was the paper lined package (No. 4). Average temperature of this box was 37.0°F. (Table III). The next lowest average temperature was 51.0°F. and was found in box No. 2 which held 20 pounds of #1 ice distributed in two layers. When 20 pounds of #1 ice was placed only on the top of the lettuce center temperature of box No. 1 averaged 58.7°F., or 7.7°F. higher than box No. 2 in which ice was distributed in two layers. The fact that average temperature of the check box (No. 5) was 4.3°F. below average atmospheric temperature indicates that lettuce did not generate much heat.

It was observed that the butts of lettuce heads became very brown in the check box. This discoloration was reduced considerably in all of the iced boxes, and heads in the paper lined box showed no evidence of browning when examined on the eighteenth hour after packaging. This indicates that refrigeration reduced discoloration of butts, and that a combination of refrigeration and the reduction of air circulation with paper liners, entirely eliminated browning.

It was noted that coarse pieces of ice in the R. of L. grade caused pitting damage to the wrapper leaves of lettuce heads. Pitting was especially prominent in the bottom tier of boxes which received pressure from four boxes stacked on top. Several investigators, (26), (29), (62), have noted the same type of damage.

Lettuce in the check box, No. 5, showed considerable wilt by the fifteenth hour, but lettuce in all of the iced boxes was crisp. It was noted that ice was melted by the fifteenth hour in all boxes except No. 4, but that there were no signs of deterioration even at the eighteenth hour. Buyers in the market have frequently assumed that wet lettuce without refrigeration would develop rot much more rapidly than dry lettuce. Pyke and Allison (51) also found that lettuce became slimy when it was moist and not refrigerated. Observations in this experiment did not substantiate this attitude. It must be noted, however, that all lettuce packed in this experiment was free of tip burn or other damage.

Lettuce - Experiment II

Lettuce was packed and iced July 27, 1948 at the same farm that Experiment I was conducted on. This experiment was conducted over a period of nineteen hours.

Methods of packing and icing were the same as those used in Experiment I with the exception of box No. 4. This package was refrigerated with #1 ice, but amount and placement of ice was the same as that employed in Experiment I.

Temperature History of Boxes and Deterioration of Lettuce

Boxes of lettuce were iced at 2:00 p.m. At 5:00 a.m. the following morning, box temperatures were taken in the same wholesale market that Experiment I was conducted in. At 8:00 a.m. temperatures were taken at the same A.&P. store that the previous experiment terminated in.

It may be seen in Figure 10 that the paper lined box, No. 4, maintained the lowest temperature throughout the experiment. Dividing 20 pounds of #1 ice in two layers lowered average temperature of box No. 2 to 57.4°F. while average temperature of box No. 1, with 20 pounds of #1 ice placed only on the top, was 61.6°F. (Table III).

At the fifteenth hour reading, ice was melted in all boxes except box No. 4 which was lined with paper. Thus value of lining a box with paper is once more evident.

Butts of lettuce heads in the check box became very brown, but discoloration was less pronounced in the iced boxes. Lettuce butts in the paper lined crate showed only slight indication of browning.

At the nineteenth hour, 25% of the unrefrigerated heads (Box No. 5) showed small lesions of rot at the base of the wrapper leaves. Lettuce in the other boxes was in good condition.

Lettuce - Experiment III

Lettuce was iced July 28, 1948. The experiment was conducted over a period of 24 hours.

Four methods of packaging were used:

Box No. 1. R. of L. ice (20 pounds placed on top of package only).

Box No. 2. R. of L. ice (10 pounds placed on top; 10 pounds placed in center).

Box No. 3. R. of L. ice (10 pounds placed on top; 10 pounds placed in center. Package lined with wet-strength paper).

Box No. 4. Check - no ice.

Temperature History of Boxes and Deterioration of Lettuce

Lettuce was iced at 3:00 p.m. and package temperatures were taken hourly through 7:00 p.m. The following morning at 6:00 a.m. temperature of boxes was recorded in the wholesale market. At 8:00 and 9:00 a.m. and 3:00 p.m. temperatures were taken at the retail store.

It will be noted that the paper lined box, No. 3, maintained the lowest temperature throughout this experiment (Fig. 11). The next lowest average temperature, found in box No. 2, was 8.3°F. higher than the paper lined box, (Table III). Box No. 2 with 20 pounds of R. of L. ice distributed in two layers maintained an average temperature which was 15.2°F. below the average temperature of box No. 1 with the same grade and amount of ice placed only on the top of the package. Thus further evidence is found to support the recommendation that ice be distributed in two layers rather than merely on the top of the package.

Butt discoloration of lettuce heads was similar to that described for Experiments I and II.

Lettuce - Experiment IV

Lettuce was packaged and iced July 29, 1948. The experiment was conducted over a period of eighteen hours.

Methods of icing and packaging were the same for boxes No. 1 and No. 2. However, box No. 3 had 20 pounds of R. of L. ice placed on the top of the package. Box No. 4 was iced with 10 pounds of #1 ice placed in the center and 10 pounds placed on the top. In addition, this box was lined with paper. Box No. 5 was the check.

Temperature History of Boxes and Deterioration of Lettuce

Lettuce was iced at 3:00 p.m. and crate temperatures were recorded each hour through 7:00 p.m. At 6:00 a.m. the following morning, package temperatures were recorded in the wholesale market. Temperatures were taken at 8:00 and 9:00 a.m. in the retail store. It will be noted in Figure 12 that similar package temperature relationships exist as were found in boxes of the three preceding experiments which were iced and packed by corresponding methods. Average temperature of the paper lined box, No. 4, was 35.4°F. (Table III). Again the crate with a paper liner maintained the lowest temperature.

Butt discoloration of the several treatments in this experiment was similar to that described for Experiments I and II.

Lettuce - Experiment V

Boxes were packed and iced August 4, 1948. This experiment lasted eighteen hours.

The same methods of packaging were used as are listed for Experiment III.

Temperature History of Boxes and Deterioration of Lettuce

Boxes were iced at 2:00 p.m. and temperatures were recorded to 5:00 p.m. At 5:00 a.m. the following morning, package temperatures were noted in the wholesale market, and at 8:00 a.m. temperatures were taken in the retail store.

Package temperatures follow the same trends as were noted in the first three lettuce experiments (Fig. 13). The paper lined box, No. 3, maintained an average temperature of 36.7°F. This was the lowest package temperature of the experiment (Table III). Box No. 1 in which 20 pounds of R. of L. ice was placed entirely on the top, had an average temperature 13.5°F. higher than box No. 2 in which the same grade and amount of ice was distributed in two layers.

On the eighteenth hour of this experiment only the paper lined box, No. 3, had much ice remaining. Ice had almost completely melted in the other boxes.

The same observations were made on lettuce butt discoloration as are explained in Experiments I and II. Some of the heads in the current experiment were not compact, and these heads showed initiation of rot at the eighteenth hour after icing.

Lettuce - Experiment VI

Lettuce was packed and iced August 5, 1948. The experiment was conducted over a period of seventeen hours.

Method of Packing and Icing

Four methods of packaging were used:

Box No. 1. #1 ice (20 pounds placed on top of package only).

Box No. 2. R. of L. ice (20 pounds placed on top of package only).

Box No. 3. R. of L. ice (10 pounds placed on top; 10 pounds placed in center).

Box No. 4. Check - no ice.

Temperature History of Boxes and Deterioration of Lettuce

Lettuce was iced at 3:00 p.m. and box temperatures were recorded hourly until 6:00 p.m. At 6:00 a.m. the following morning package temperatures were taken in the wholesale market, and at 8:00 a.m. they were recorded at the retail store.

It will be noted in Figure 14 that none of the package temperatures dropped below 40°F. Boxes No. 1 and 2 in which ice was placed only on the top, had consistently higher temperatures than box No. 3 in which the same amount of ice was divided in two layers. The differences in average temperature among the iced boxes is slight. There is only a 4.8°F. spread between the highest average temperature and lowest average temperature of the three iced boxes (Table III).

At the fifteenth hour of the experiment only box No. 3, with R. of L. ice distributed in two layers, had ice remaining.

The same butt discoloration relationships were observed as described for Experiments I and II.

Table III
Average Temperature of Lettuce Packages as Related to
Grade of Ice and Method of Ice Placement

Grade of ice and method of placement	Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI
#1 ice 20 lbs., top placement only	58.7°F.	61.6°F.		56.3°F.		49.5°F.
#1 ice 10 lbs. top; 10 lbs. center	51.0°F.	57.4°F.				
R. of L. ice 20 lbs., top placement only	63.0°F.	67.3°F.	63.3°F.	60.1°F.	59.2°F.	47.8°F.
R. of L. ice 10 lbs. top; 10 lbs. center, paper liner	37.0°F.	37.2°F.	39.8°F.	35.4°F.	36.7°F.	44.7°F.
R. of L. ice 10 lbs. top; 10 lbs. center			48.1°F.	49.0°F.	45.7°F.	
Check - no ice	69.0°F.	72.7°F.	70.9°F.	66.6°F.	68.9°F.	63.7°F.
Atmospheric Temperature	73.3°F.	73.8°F.	74.0°F.	74.9°F.	69.6°F.	69.0°F.

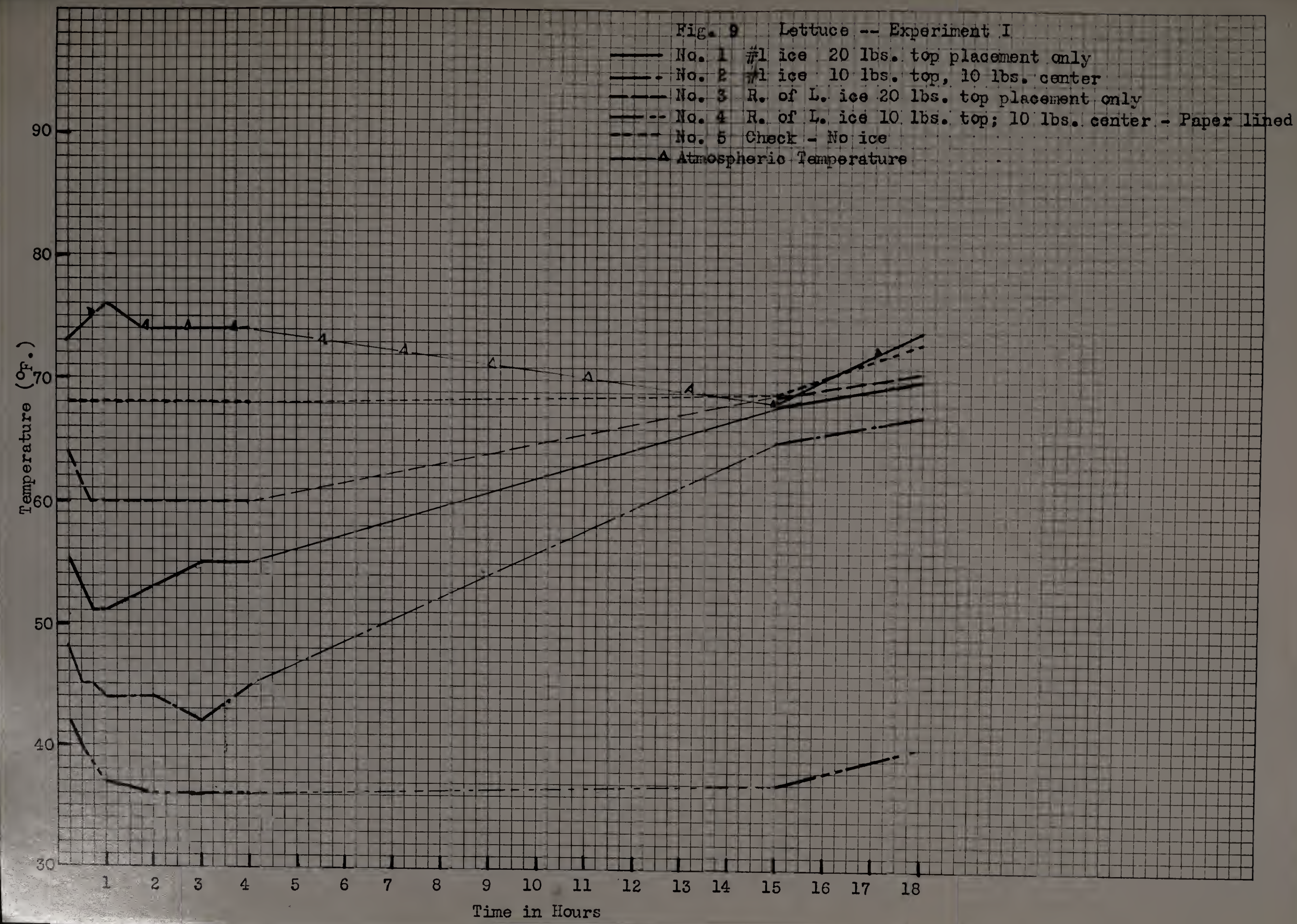


Fig. 9 Lettuce -- Experiment I
No. 1 #1 ice 20 lbs. top placement only
No. 2 #1 ice 10 lbs. top, 10 lbs. center
No. 3 R. of L. ice 20 lbs. top placement only
No. 4 R. of L. ice 10 lbs. top; 10 lbs. center - Paper lined
No. 5 Check - No ice
Atmospheric Temperature
Temperature (°F.)
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Time in Hours

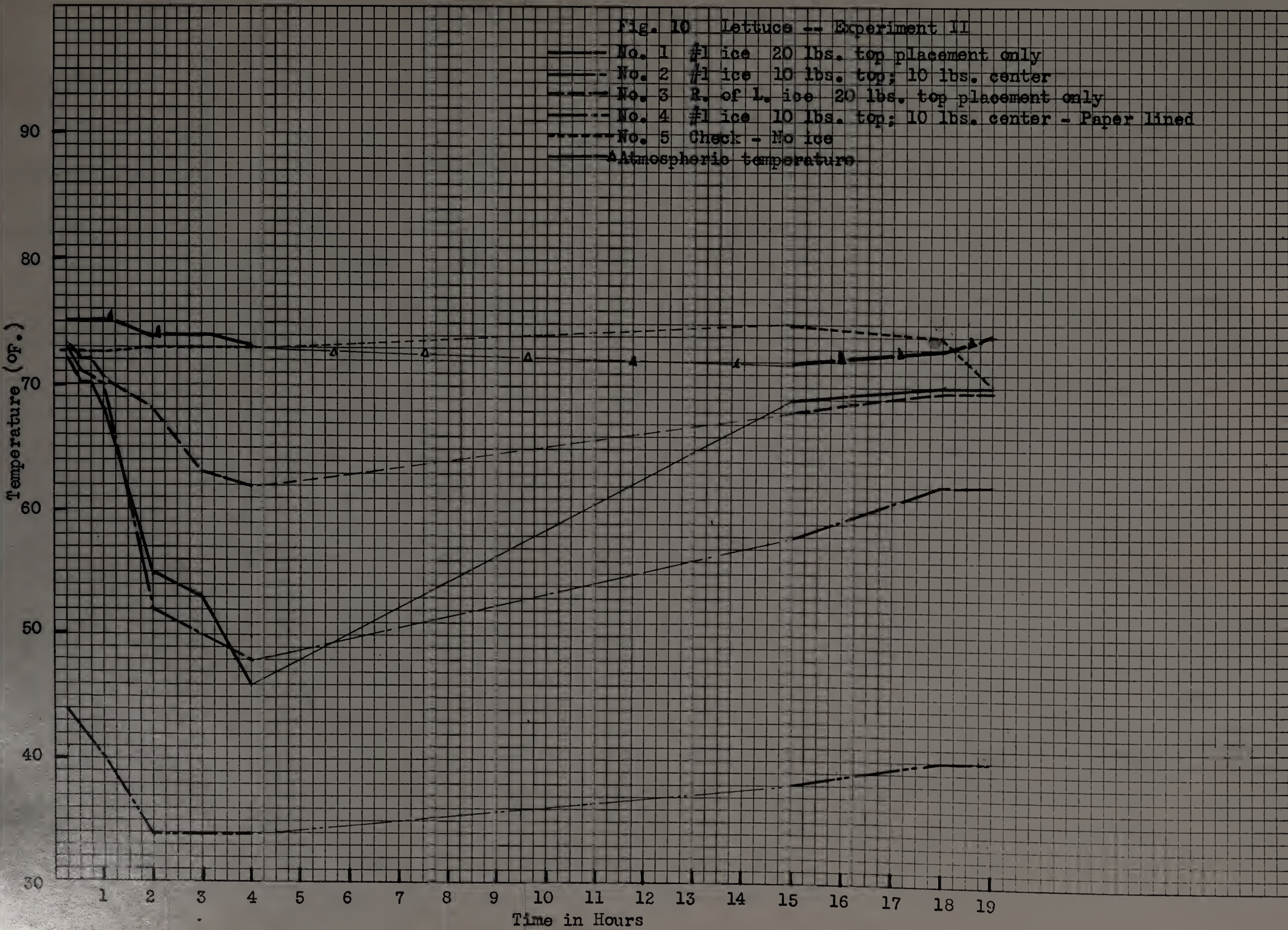


Fig. 10 Lettuce -- Experiment II
No. 1 #1 ice 20 lbs. top placement only
No. 2 #1 ice 10 lbs. top; 10 lbs. center
No. 3 R. of L. ice 20 lbs. top placement only
No. 4 #1 ice 10 lbs. top; 10 lbs. center - Paper lined
No. 5 Check - No ice
Atmospheric temperature
Temperature (oF.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Time in Hours

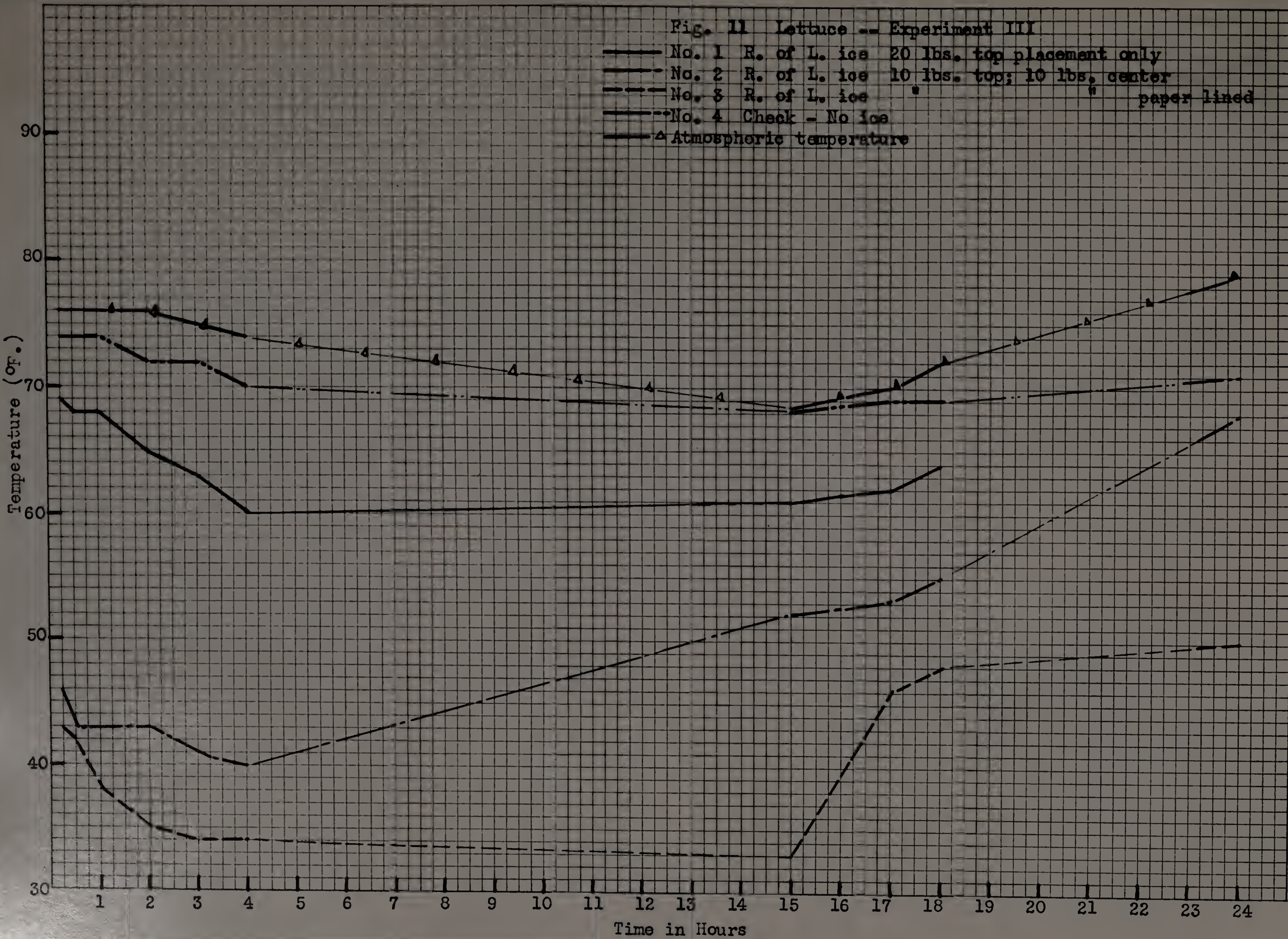


Fig. 11 Lettuce -- Experiment III
No. 1 R. of L. ice 20 lbs. top placement only
No. 2 R. of L. ice 10 lbs. top; 10 lbs. center
No. 3 R. of L. ice " " paper lined
No. 4 Check - No ice
Atmospheric temperature
Temperature (oF.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Time in Hours

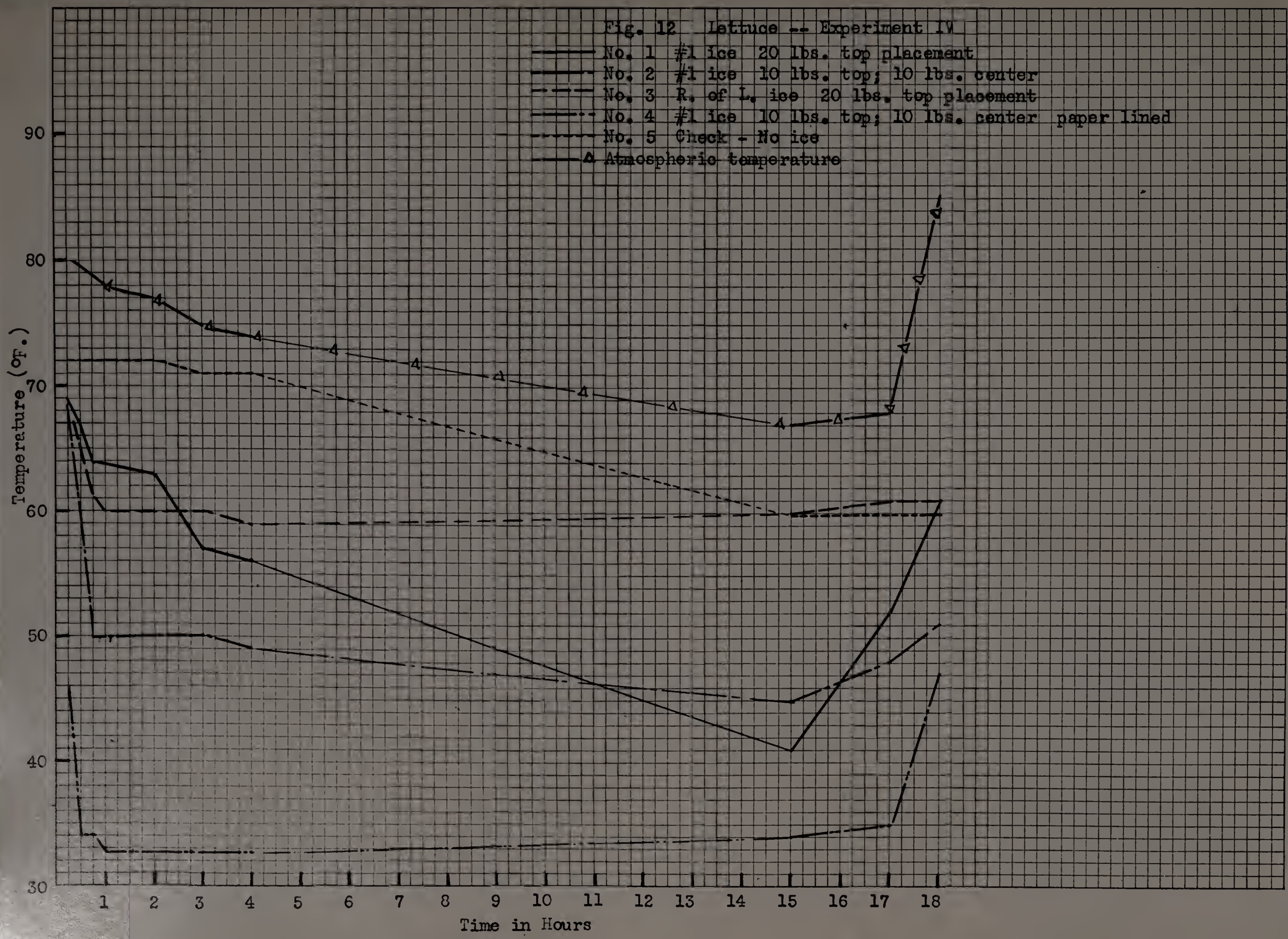


Fig. 12 Lettuce -- Experiment IV
No. 1 #1 ice 20 lbs. top placement
No. 2 #1 ice 10 lbs. top; 10 lbs. center
No. 3 R. of L. ice 20 lbs. top placement
No. 4 #1 ice 10 lbs. top; 10 lbs. center paper lined
No. 5 Check - No ice
Atmospheric temperature
Temperature (°F.)
30
40
50
60
70
80
90
Time in Hours
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

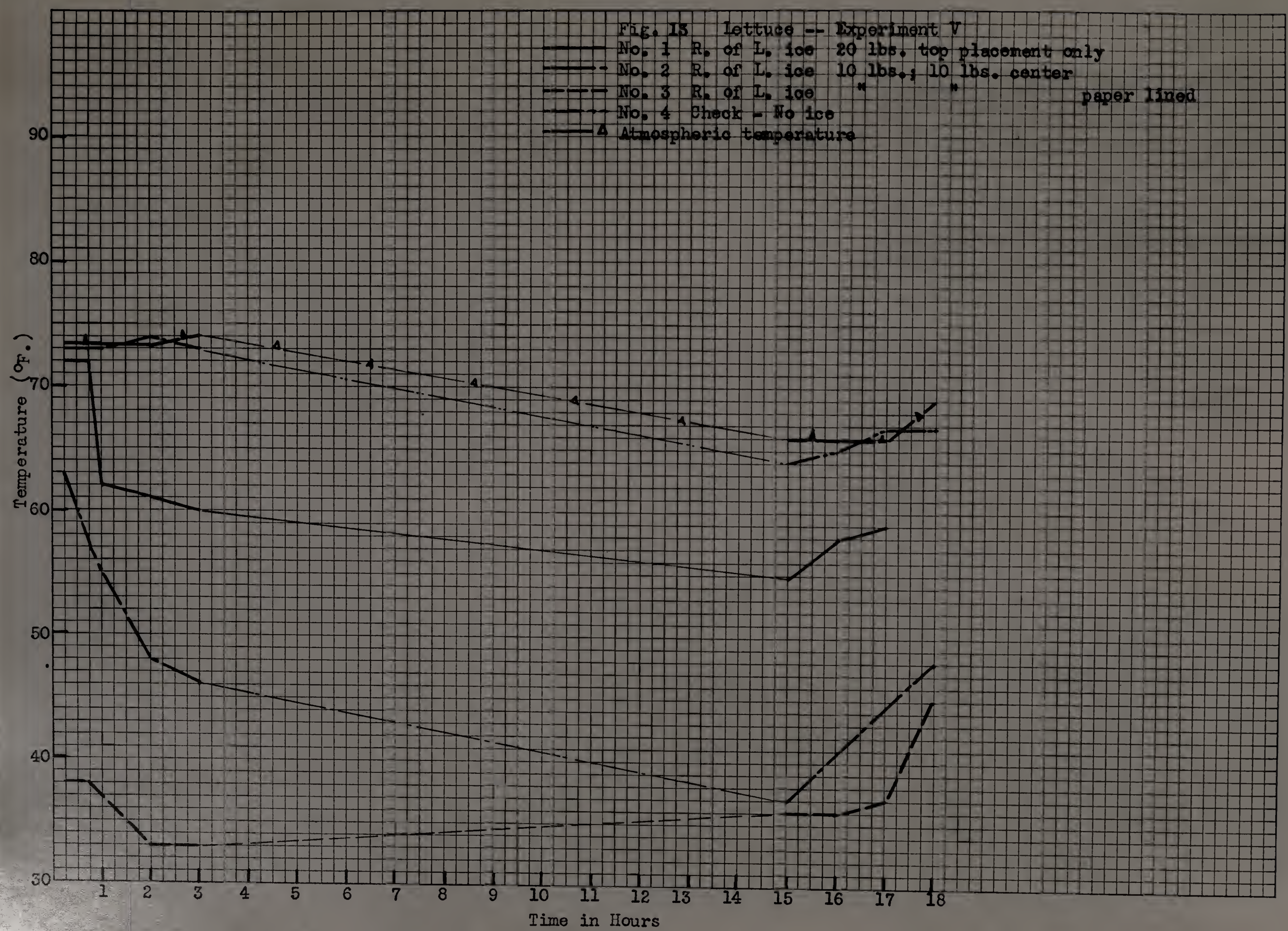


Fig. 13 Lettuce -- Experiment V
No. 1 R. of L. ice 20 lbs. top placement only
No. 2 R. of L. ice 10 lbs.; 10 lbs. center
No. 3 R. of L. ice " " paper lined
No. 4 Check - No ice
Atmospheric temperature
Temperature (°F.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Time in Hours

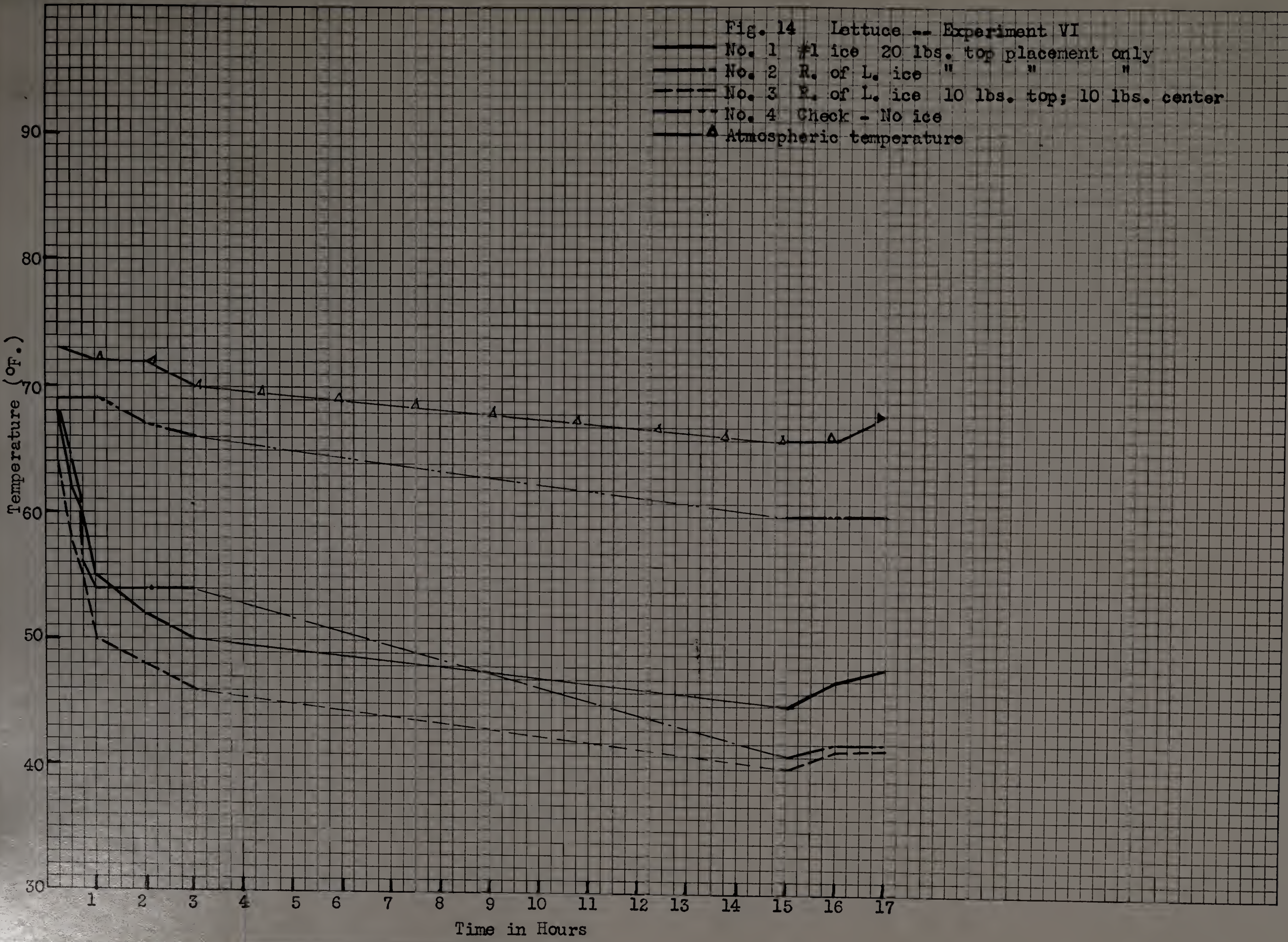


Fig. 14 Lettuce -- Experiment VI

Package Icing Spinach - Experiment I

Spinach was iced August 10, 1947 in the packing shed of De Vincent Brothers Farm, Waltham, Massachusetts. The experiment was conducted over a period of seventeen hours.

Methods of Packing and Icing

Spinach was harvested between 11:00 a.m. and 12:00 a.m. It was field packed in standard Massachusetts bushel boxes which measure 17½" x 17½" x 7-1/16". Boxes were iced and one lot, designated as A, was left in the packing shed for four hours. Following the four-hour period, these boxes were placed in the cooler over night storage. The other lot, designated as B, was placed immediately in a cold-air cooler which was maintained at approximately $40^{o}F$.

The following methods of packing and handling were used:

Lot A - left in packing shed 4 hours before placed in cooler.

Box No. 1. Grower's method #1 ice (3½ pounds in center of package; 3½ pounds on top).

Box No. 2. #2 ice (Same amount and placement as No. 1).

Box No. 3. #3 ice (Same amount and placement as No. 1).

Box No. 4. Check - no ice.

Lot B - boxes placed directly in cooler after icing. (Cooler temperature 40°F.)

Box No. 1. Same as A-1.

Box No. 2. Same as A-2.

Box No. 3. Same as A-3.

Temperature History of Boxes

Spinach was iced at 1:00 p.m. Lot A was left in the packing shed for 4 hours, and Lot B was placed in the cooler. At 5:00 p.m. Lot B was put in the cooler. Temperatures of all boxes were recorded the following morning at 6:00 a.m.

From Table IV it may be readily observed that packages placed directly in the cold-air cooler maintained average temperatures which were considerably below boxes which were left in the packing shed for four hours. Average temperature of the #2 iced box (Lot B, No. 2) was 10.2°F. lower in the cold air storage lot than in the corresponding box (Lot A, No. 2) which was left in the shed four hours. Ice melted from the top of all packages which were left in the packing shed for four hours. After boxes were placed in the cooler which was maintained at 40°F., there was no apparent meltage.

Boxes of Lot A were placed in the cooler after the fourth hour and it is interesting to note the manner in which all iced boxes attained a temperature of 33° to

35°F. during the thirteen hours they were stored in the cooler (Fig. 15).

Temperature of the check box was lowered only 6°F. during the thirteen hours of cold air storage.

Spinach - Experiment II

Crates of spinach were iced and packed September 8, 1948 at the same farm that Experiment I was conducted on the preceding year. This experiment lasted only seven hours.

Methods of Packing and Icing

The quantity of ice used by the grower had approximately doubled since the 1947 experiment. Twelve pounds of ice was used per standard bushel box of produce.

Four methods of packing were used:

Box No. 1. #1 ice (6 pounds in center of package; 6 pounds on top).

Box No. 2. #3 ice (Same amount and placement as No. 1).

Box No. 3. #4 ice (Same amount and placement as No. 1).

Box No. 4. Check - no ice.

Temperature History of Boxes

Spinach was iced at 3:00 p.m. and remained in the packing shed until 7:00 p.m. Boxes were then loaded on an open stake-body truck and transported to the Faneuil

Hall Market in Boston, Massachusetts. Temperatures were taken in this market at 9:00 and 10:00 p.m.

Reversal of temperatures was apparent in this experiment. Small sizes of ice lowered temperature most rapidly, but the large sizes maintained refrigeration at a lower level, (Fig. 16). It will be noted that #1 ice maintained the lowest average temperature, 37.8°F., while the box which was iced with the #4 grade had the highest average temperature, 56.8°F. (Table IV). Thus the smallest sizes of ice produced the best over-all refrigeration, and this efficiency decreased progressively as larger sizes of ice were used in the boxes.

Packages with the larger sizes of ice had more ice remaining after six hours than those with smaller sizes. The #1 ice, box No. 1, was practically all melted while the #4 ice, box No. 3, was approximately half melted.

Table IV
Average Temperature of Boxes of Spinach as Related to Size of Ice and Placement in a Cold-Air Storage Room

Experiment I

Size of ice	Lot A - left in packing shed 4 hours	Lot B - placed directly in cooler
#1	33.0°F.	33.0°F.
#2	43.2°F.	33.0°F.
#3	43.4°F.	40.4°F.
#4	-	-
Check - no ice	71.2°F.	-
Atmospheric Temperature	76.2°F.	40.0°F.

Experiment II

Size of ice	Average temperature
#1	37.8°F.
#3	44.3°F.
#4	56.8°F.
Check - no ice	72.0°F.

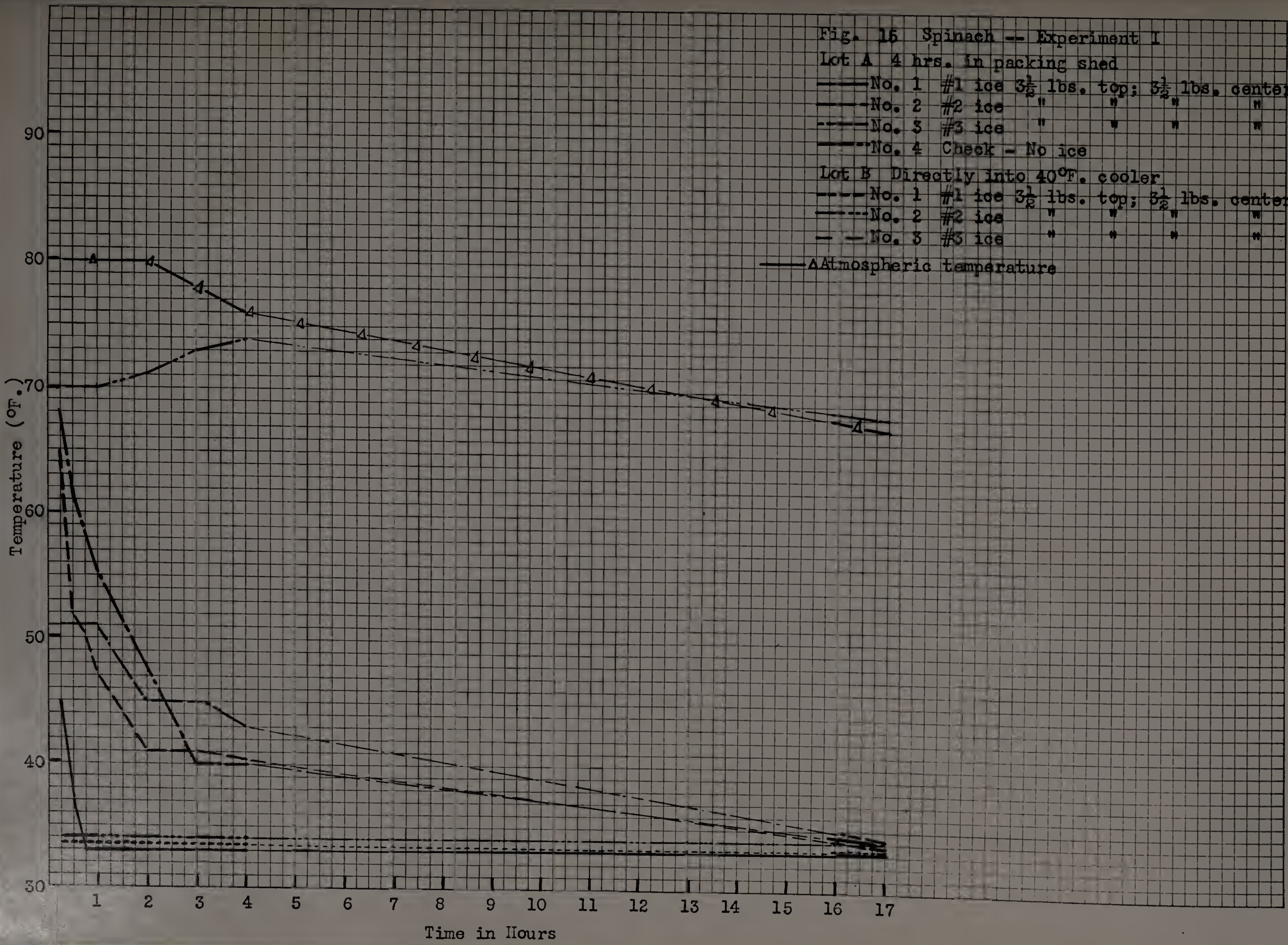


Fig. 16 Spinach -- Experiment I

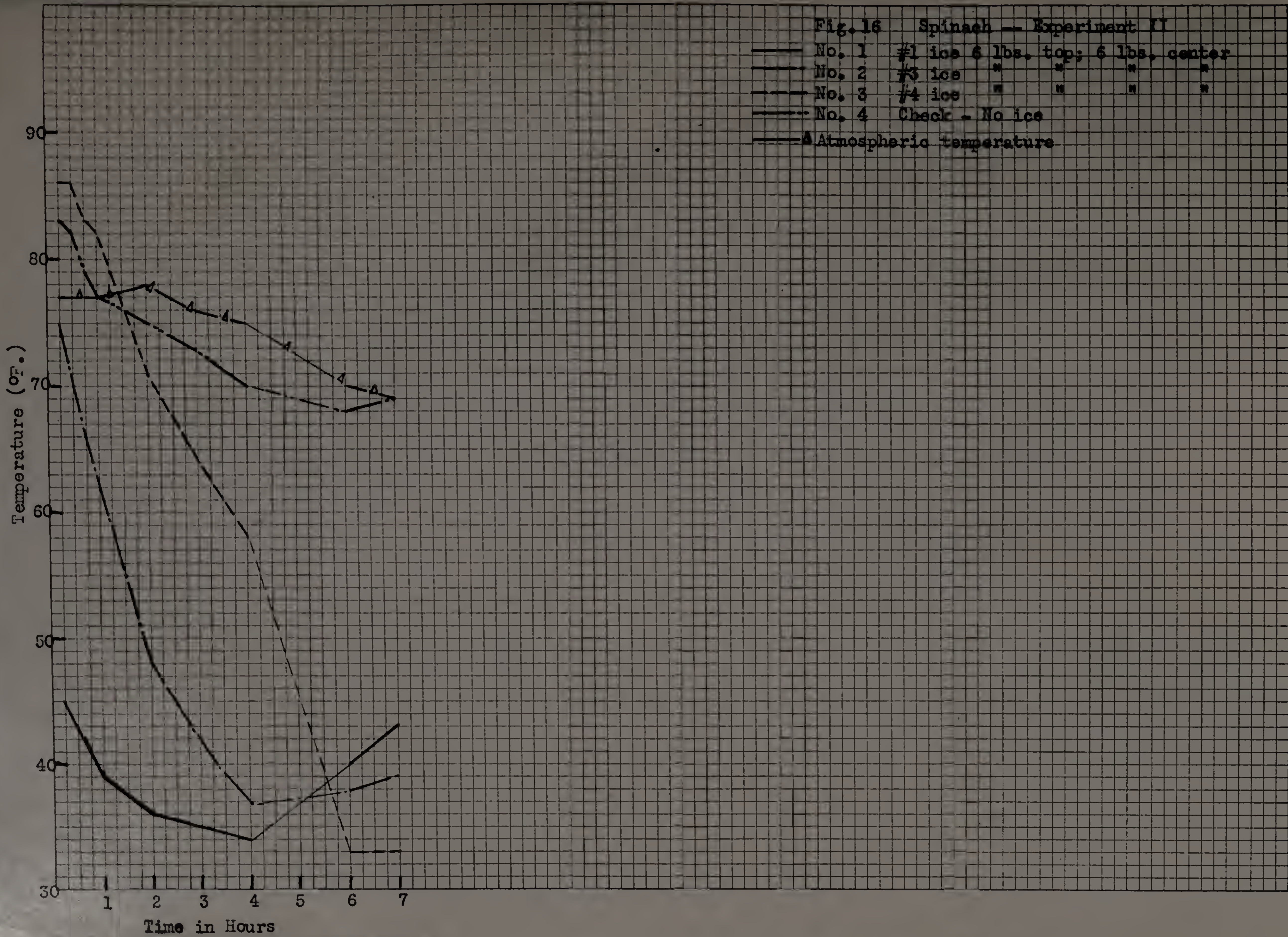


Fig. 16 Spinach -- Experiment II
No. 1 #1 ice 6 lbs. top; 6 lbs. center
No. 2 #3 ice " " " "
No. 3 #4 ice " " " "
No. 4 Check - No ice
Atmospheric temperature
Temperature (°F.)
30
40
50
60
70
80
90
Time in Hours
1
2
3
4
5
6
7

Package Icing Sweet Corn

Four experimental runs were made in 1947 and two runs in 1948.

Experiment I

Crates of sweet corn were iced August 19, 1947 at the farm of Earle Parsons, Northampton, Massachusetts. On August 20 crates were followed to an A.&P. store in Northampton. Corn remained in a packing shed 12 hours the first day, and was observed on an iced retail store counter for 2 hours the second day.

Method of Packing and Icing

Corn was harvested between 1:00 p.m. and 3:00 p.m. It was transported to the packing shed and repacked with 60 ears per Bruce crate.

The grower's method of packing was to place 30 ears of corn in the bottom of a crate and spread 11 pounds of #1 ice over this. A second layer of 30 ears was placed over this and topped with 11 pounds of #1 ice. A total of 22 to 25 pounds of ice was placed in each crate.

Six methods of packaging were employed in this experiment: (Fig. 17).

Crate No. 1. Grower's method - #1 ice (11 pounds on top of package and 11 pounds in center).

Crate No. 2. #2 ice (11 pounds in each of 2 layers).

Crate No. 3. #3 ice (11 pounds in each of 2 layers).

Crate No. 4. #4 ice (11 pounds in each of 2 layers).

Crate No. 5. #1 ice (11 pounds on top of package only).

Crate No. 6. Check - no ice.

Market Temperature History of Crates

Corn was packed and iced at 4:00 p.m. At 8:00 a.m. the following morning, packages were unloaded on an iced retail counter and identity of the six lots was lost. Temperatures between the twelfth and thirteenth hour were taken on the iced counter.

It will be noted (Fig. 17) that the temperature in crate No. 1 dropped most rapidly followed by Nos. 2, 3, 4, and 5. Smallest sizes of ice lowered temperature most rapidly and to a lower level than large sizes. A reversal of the temperature trend is found at the twelfth-hour reading. At this reading large sizes of ice reduced package temperature to a lower level than small sizes. Of particular interest is the fact that atmospheric temperature was consistently below package temperature of No. 6, which was not refrigerated. This temperature differential indicates that sweet corn generated enough heat to elevate average temperature of the uniced package 5.5°F. above average atmospheric temperature (Table V). The work of Rose et. al. (57) substantiates this observation. They found that sweet corn liberated more heat than practically any other vegetable. In crate No. 5, top placement of 11 pounds of #1 ice resulted in a slow temperature drop and average temperature for this crate was 63.3°F. This indicates that top placement of ice does not lower temperature nearly as well as both center and top placement.

After twelve hours, crate No. 4 with #4 ice was the only package which had ice remaining. The smaller grades of ice had completely melted.

Sweet Corn - Experiment II

This experiment was held August 20, 1947 on the same farm as Experiment I. Packages were followed the next morning to the A.&P. store.

Method of Packing and Icing

Grower's method of packing was the same as that used in Experiment I. Crate No. 3 was packaged in the same manner as the grower's pack crate, No. 1, but was enclosed with a crate liner of wet-strength paper. The six methods of packaging were as follows:

Crate No. 1. Grower's method - #1 ice (11 pounds on top of package and 11 pounds in center).

Crate No. 2. #1 ice (11 pounds on top of package only).

Crate No. 3. #1 ice (11 pounds in each of 2 layers, crate lined with wet-strength paper).

Crate No. 4. #2 ice (11 pounds in each of 2 layers).

Crate No. 5. #3 ice (11 pounds in each of 2 layers).

Crate No. 6. Check - no ice.

Market Temperature History of Crates

Package temperatures in this lot (Fig. 18) were appreciably lower than those in Experiment I. Similar temperature trends are found as existed in the preceding experiment. Small sizes of ice lowered temperature most rapidly, but did not carry the refrigeration effect for as long a time as did larger sizes. Large sizes dropped package temperature more slowly, but maintained refrigeration for a longer period than did small sizes. Thus a reverse temperature trend was operative. It will be noted that temperature of the paper lined crate, No. 3, reached 34°F. in fifteen minutes and remained at this low level for three hours after icing. Twelve hours after icing the paper lined crate had more ice remaining than any of the other crates.

Sweet Corn - Experiment III

This experiment was started August 27, 1947 on the farm of Albert Christopher, Agawam, Massachusetts. The following day corn was hauled to an A.&P. store on State Street, Springfield, Massachusetts. The experiment was held over a period of fifteen hours.

Methods of Packing and Icing

The grower's method was to pack 60 ears of corn in Bruce crates in the field. Crates were hauled to the packing shed where 22 pounds of #1 ice was placed on top of the corn in the package.

Seven methods of packaging were used in this experiment:

- Crate No. 1. Grower's method - #1 ice (22 pounds on top of packages).
- Crate No. 2. #2 ice (11 pounds on top of corn; 11 pounds in center of packages).
- Crate No. 3. #3 ice (11 pounds in each of 2 layers).
- Crate No. 4. #4 ice (11 pounds in each of 2 layers).
- Crate No. 5. #1 ice (11 pounds in each of 2 layers, crate lined with wet-strength paper).
- Crate No. 6. Water soaked only (temperature of water 70^{o}F.).
- Crate No. 7. Check - no ice.

Market Temperature History of Crates

Corn was harvested between 3:00 p.m. and 5:00 p.m. and it was packed at 6:00 p.m. At 6:00 a.m. the following morning, crates left the packing house and arrived at a retail store at 9:00 a.m.

The reverse temperature trend is evident in this experiment (Fig. 19). It will be noted that the crate in which a paper liner was used, No. 5, maintained an average temperature of 37°F. (Table V). This was the lowest temperature of any of the crates during the first three hours after packing. Of particular importance is the fact that after 12 hours, temperature of this crate was 34°F., and remained at this low level through to the end of the experiment. A similar temperature relationship was noted in the paper lined crate (No. 3) of Experiment II.

Crate No. 2 with #2 ice had only a few pieces of ice remaining after 11 hours from the time of icing. Crate No. 3 with #3 ice had somewhat more ice remaining, and crate No. 4 with #4 ice had still more ice remaining. Very little ice was melted in the paper lined crate, No. 5, after 11 hours. Hence it was found that the larger sizes of ice had more lasting value than the smaller sizes.

Temperatures in both the check crate and the crate soaked with tap water were considerably higher than the atmospheric temperature. It will be noted that temperature in the water-soaked crate was reduced very little, and that average temperature of this crate for the entire experiment was 73.6°F. (Table V). Average atmospheric temperature was 6.8°F. less than temperature of the water-soaked crate. Thus it would appear that wetting the corn accelerated heat evolution.

Sweet Corn - Experiment IV

Sweet corn was iced August 28, 1947 at the farm that Experiment III was conducted on and it was hauled to the same retail store. The experiment was held over a period of 15 hours. The same methods of icing and packing were used as in Experiment III.

Market Temperature History of Crates

The temperatures of the various crate treatments closely parallel those of Experiment III. Here again it will be observed that temperature of the paper lined crate, No. 5, is consistently lower than the temperature of any other crate (Fig. 20).

Average temperature of the crate soaked with tap water was 82°F. or 12.8°F. higher than the atmospheric temperature (Table V). This indicates that water has no refrigerating value. Crate temperature of the check packages averaged 85.2°F. while atmospheric temperature averaged 69.2°F. Thus the check temperature was 16.0°F. higher than the atmospheric temperature.

The rate of ice meltage for the various grades was the same as that described in Experiment III.

Sweet Corn - Experiment V

Corn was iced August 31, 1948 at the same farm that Experiment IV was conducted on. It was hauled the following morning to an A.&P. store on Memorial Avenue, West Springfield, Massachusetts. This experiment was conducted over a period of 25 hours.

Methods of Packing and Icing

Corn was harvested between 1:00 and 3:00 p.m. It was transported to a packing shed and iced at 4:00 p.m. Crates arrived at a retail store at 3:00 a.m. and were placed in a refrigerator box.

Methods of packing were the same as those described for Experiment III except that crate No. 6 was deleted from this experiment, and #1 ice was used in crate No. 5 instead of the R. of L. grade.

Market Temperature History of Crates

The reverse temperature trend is apparent in this experiment (Fig. 21). Similar relationships are found as were noted in Experiment IV. The crate which was lined with paper had an average temperature of 39.9°F. (Table V). The package with 22 pounds of ice placed only on the top had an average temperature of 58.2°F., or an average temperature of 18.3°F. above the paper lined crate.

Twenty-five hours from the time of icing the paper lined crate, No. 5, had approximately half of the ice remaining. Crates with #3 and #4 ice had a small amount of ice in the center layer after twenty-five hours, but the smaller grades were completely melted.

Average temperature of the check package was 12.3°F. above atmospheric temperature which indicates considerable heat evolution by the commodity. At 10:00 a.m. crates were placed in a refrigerator box held at 40°F., and at 5:00 p.m., seven hours later, temperature of all crates did not vary more than eight degrees.

Sweet Corn - Experiment VI

Corn was harvested and iced September 2, 1948 at the same farm that Experiments III and IV were made on. Crates were taken to the same retail store that Experiment V was conducted at. This experiment lasted 16 hours.

Methods of Packing and Icing

Corn was harvested between 2:00 and 4:00 p.m. It was iced in the packing shed at 6:00 p.m. Crates arrived at the retail store at 9:00 a.m. the following morning.

Six methods of packaging were used in this experiment:

Crate No. 1. Grower's method - #1 ice (22 pounds on top of package only).

Crate No. 2. #2 ice (11 pounds in each of 2 layers).

Crate No. 3. #3 ice (11 pounds in each of 2 layers).

Crate No. 4. #4 ice (11 pounds in each of 2 layers).

Crate No. 5. #1 ice (11 pounds in each of 2 layers, paper lined).

Crate No. 6. Check - no ice.

Market Temperature History of Crates

A reverse temperature trend is evident in this experiment (Fig. 22). The paper lined crate had an average temperature of only 0.8°F. lower than the crate with #2 ice (Table V). This is the only experiment in which the paper lined crate did not reduce temperature appreciably below crates iced by other methods. Top placement of 22 pounds of #1 ice resulted in an average center temperature of 67.2°F. while crates having the same quantity of ice distributed in two layers averaged 48° to 55.7°F. (Table V).

Comparison of Average Market Temperatures in the Six Corn Experiments

It will be observed in Experiments I and II (Table V) that placement of 11 pounds of #1 ice on the top of the corn lowered average crate temperature only 23.7° and 12.5°F. respectively below the check packages. Placement of 11 pounds of the same grade in the center, and 11 pounds on the top lowered average temperature 46.2°F. below check packages in Experiment I, and 37.0°F. below check packages in Experiment II.

Average temperature of all paper lined crates was $40.1^{\circ}F$. (Table V), while average temperature of crates iced similarly but not paper lined was $45.6^{\circ}F$. It will be noted that average temperature of the paper lined crates was $5.5^{\circ}F$. below the unlined crates. This demonstrates the manner in which paper liners serve to hold refrigeration within a package.

A trend seems operative between grade of ice and temperature level attained. For instance, 22 pounds of #1 ice in a paper lined crate produced an average temperature of $40.1^{\circ}F$. (Table V). The same amount and placement of #2 ice resulted in an average temperature of 45.6°. All conditions were the same except that #3 grade ice was used. This resulted in a temperature of $48.4^{\circ}F$., and when #4 grade was used, average temperature was $52.7^{\circ}F$. Thus it will be noted that in these experiments, smaller sizes of ice had the greatest refrigerating value.

Table V
Average Temperature of Corn Packages as Related to Size of Ice
And Method of Ice Placement

Exp. I	Exp. II	Exp. III	Exp. IV	Exp. V	Exp. VI	Average of All Crates	Size of Ice and Method of Placement
63.3°F.	62.3°F.						#1 ice 11 pounds - top only.
		49.4°F.	69.8°F.	58.2°F.	67.2°F.		#1 ice 22 pounds - top only.
40.8°F.	37.8°F.						#1 ice 11 pounds top; 11 pounds ctr.
	35.3°F.	37.0°F.	34.8°F.	39.9°F.	48.0°F.	40.1°F.	#1 ice 11 pounds top; 11 pounds package enclosed with paper liner.
42.5°F.	38.0°F.	42.4°F.	48.4°F.	48.3°F.	48.8°F.	45.6°F.	#2 ice 11 pounds top; 11 pounds ctr.
48.0°F.	40.3°F.	47.6°F.	51.8°F.	50.1°F.	49.5°F.	48.4°F.	#3 ice 11 pounds top; 11 pounds ctr.
46.8°F.		50.8°F.	56.4°F.	52.4°F.	55.7°F.	52.7°F.	#4 ice 11 pounds top; 11 pounds ctr.
		73.6°F.	82.0°F.				Soaked with tap water - no ice.
87.0°F.	74.8°F.	74.2°F.	85.2°F.	71.1°F.	72.5°F.		Check - no ice
81.5°F.	68.7°F.	66.8°F.	69.2°F.	58.8°F.	61.7°F.		Atmospheric Temperature

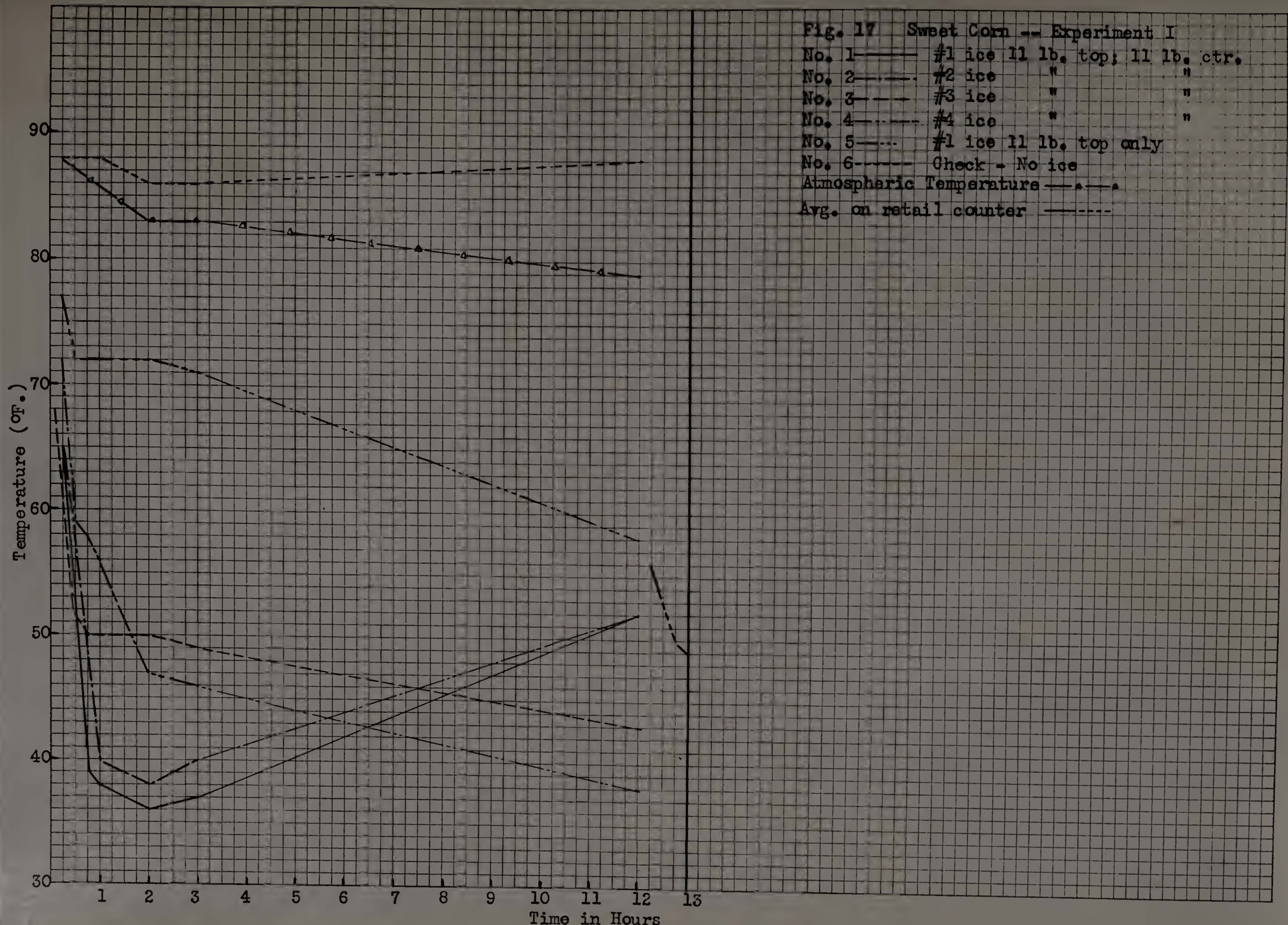


Fig. 17 Sweet Corn -- Experiment I
No. 1 #1 ice 11 lb. top; 11 lb. ctr.
No. 2 #2 ice " "
No. 3 #3 ice " "
No. 4 #4 ice " "
No. 5 #1 ice 11 lb. top only
No. 6 Check - No ice
Atmospheric Temperature
Avg. on retail counter
Temperature (oF.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
Time in Hours

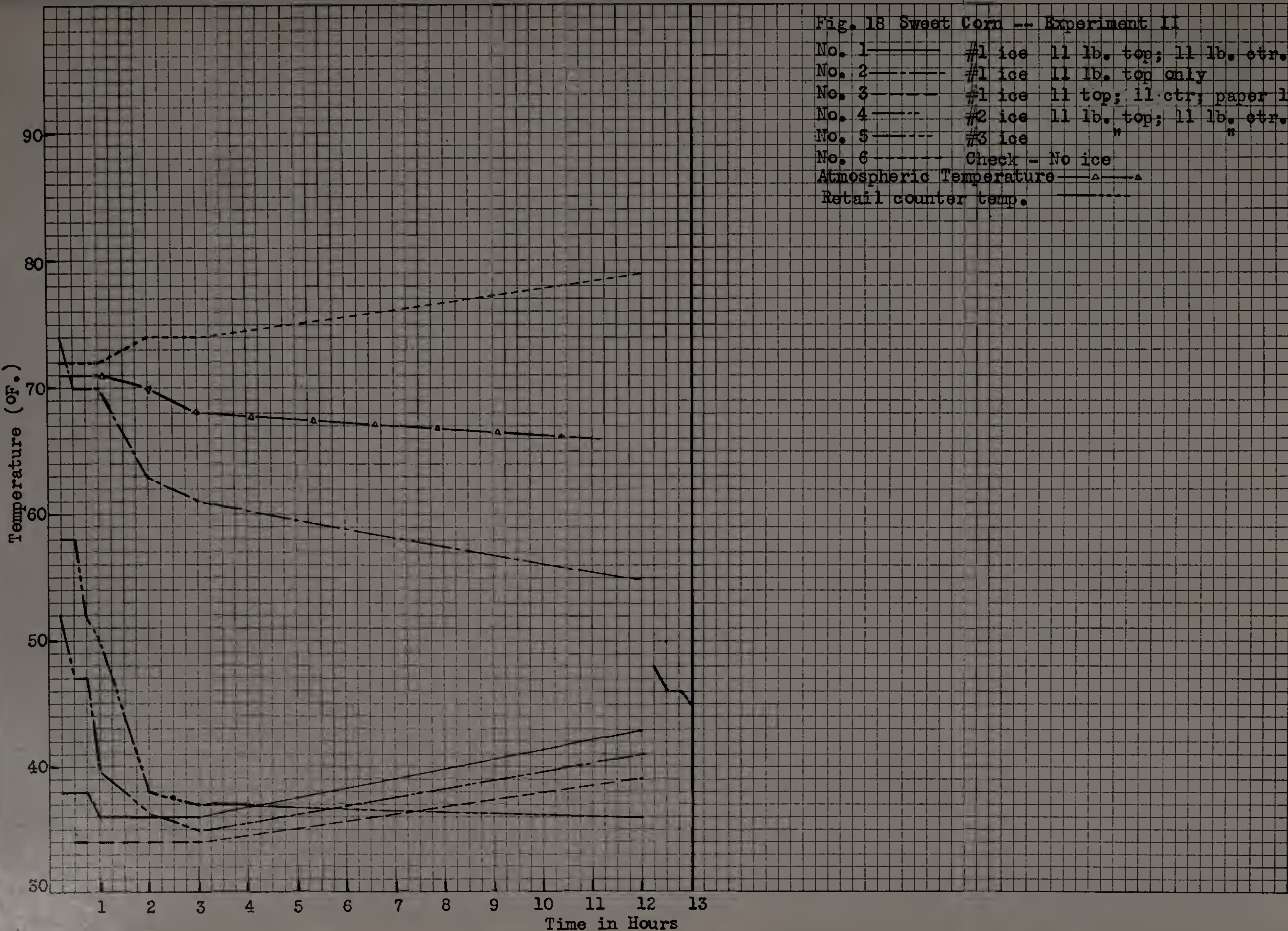
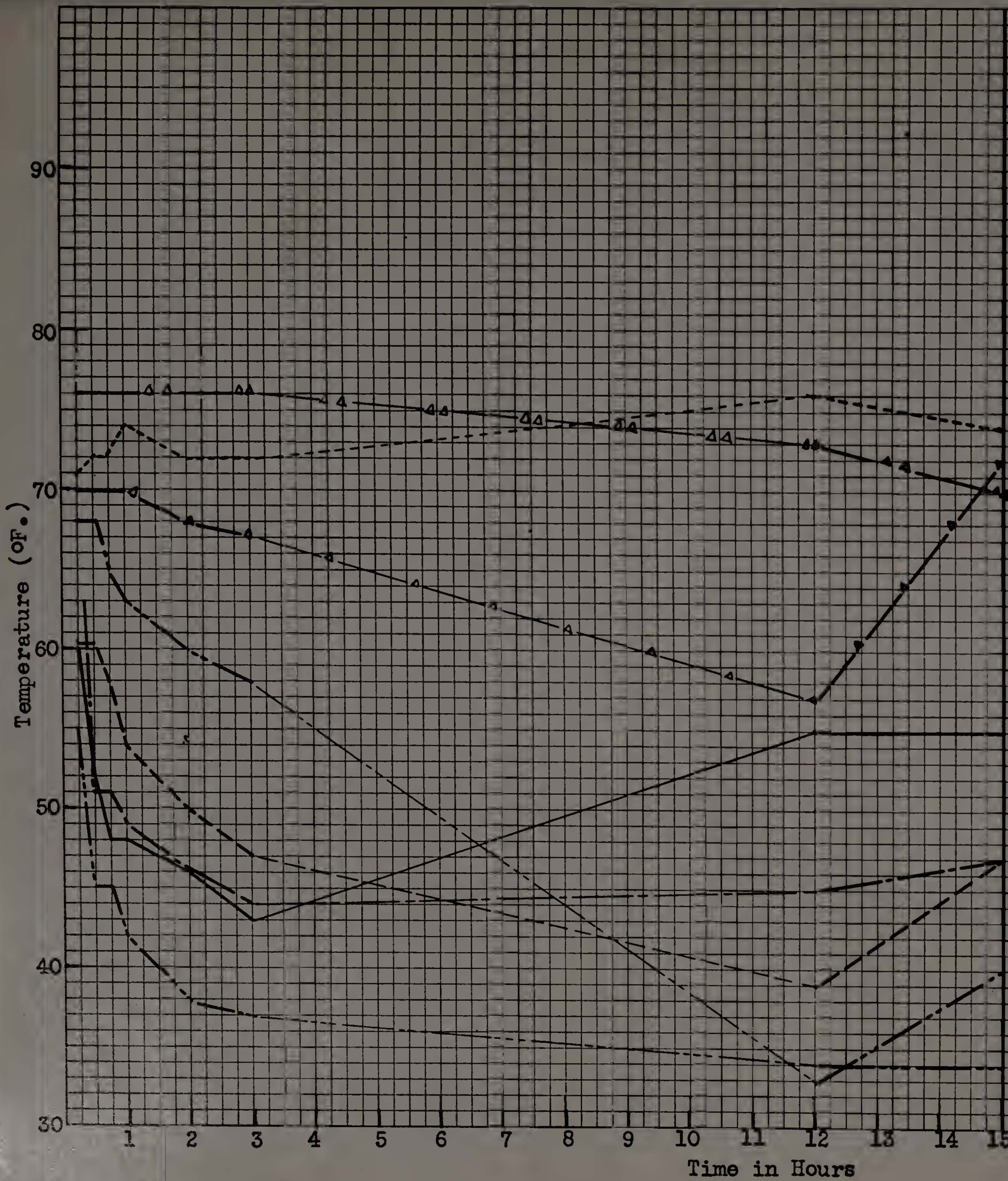


Fig. 18 Sweet Corn -- Experiment II

Fig. 19 Sweet Corn — Experiment III

No. 1 ———	#1	22 top only
No. 2 —·—·—	#2	11 top; 11 ctr.
No. 3 — — —	#3	" "
No. 4 —··—··—	#4	" "
No. 5 ——·—··	#1	" " Paper L.
No. 6 - - - - -		Water soaked only
No. 7 ——△△		Check - No ice

Atmospheric Temperature ——△——△



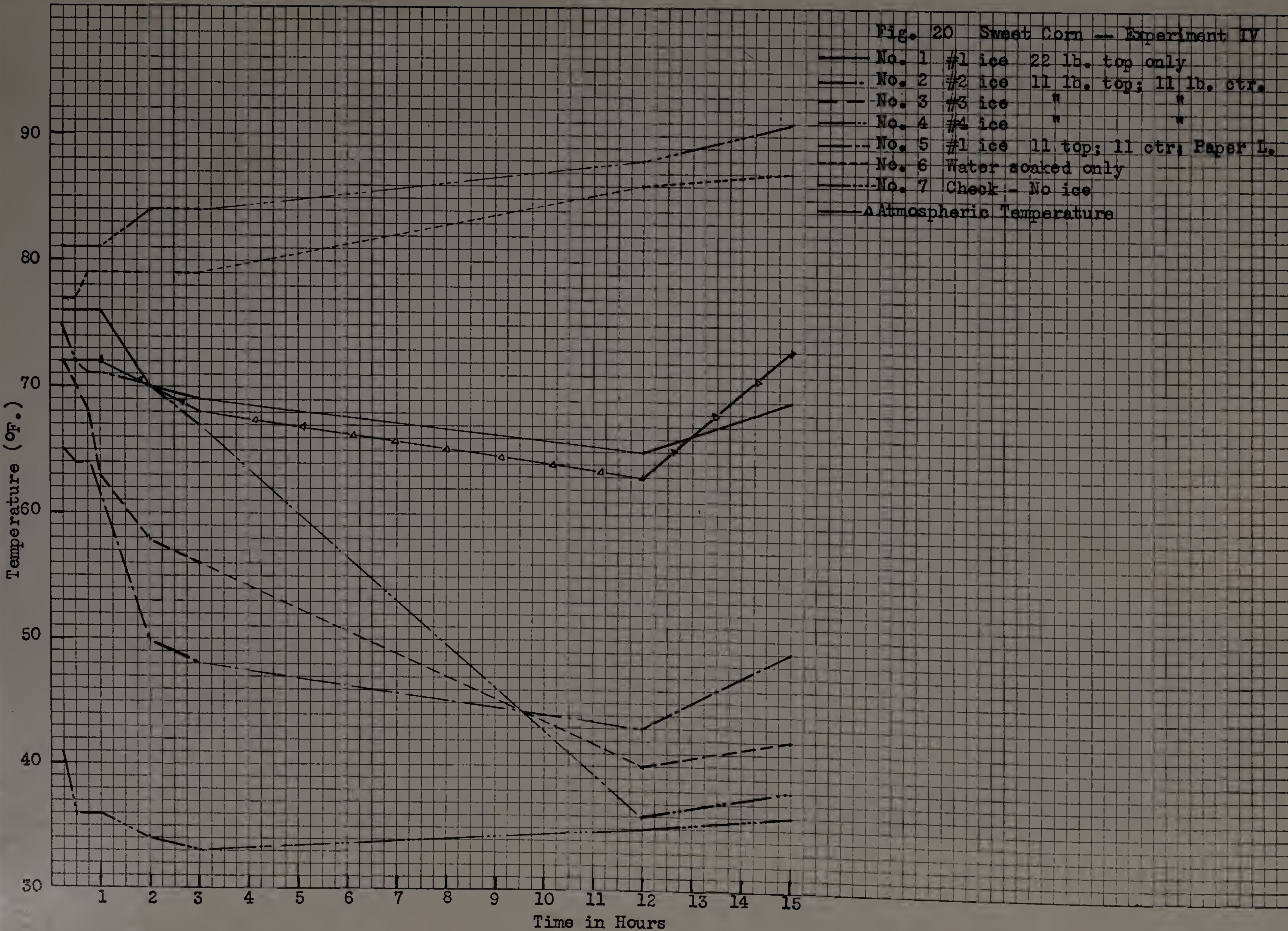


Fig. 20 Sweet Corn — Experiment IV
No. 1 #1 ice 22 lb. top only
No. 2 #2 ice 11 lb. top; 11 lb. ctr.
No. 3 #3 ice " "
No. 4 #4 ice " "
No. 5 #1 ice 11 top; 11 ctr; Paper L.
No. 6 Water soaked only
No. 7 Check - No ice
Atmospheric Temperature
Temperature (°F.)
30
40
50
60
70
80
90
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Time in Hours

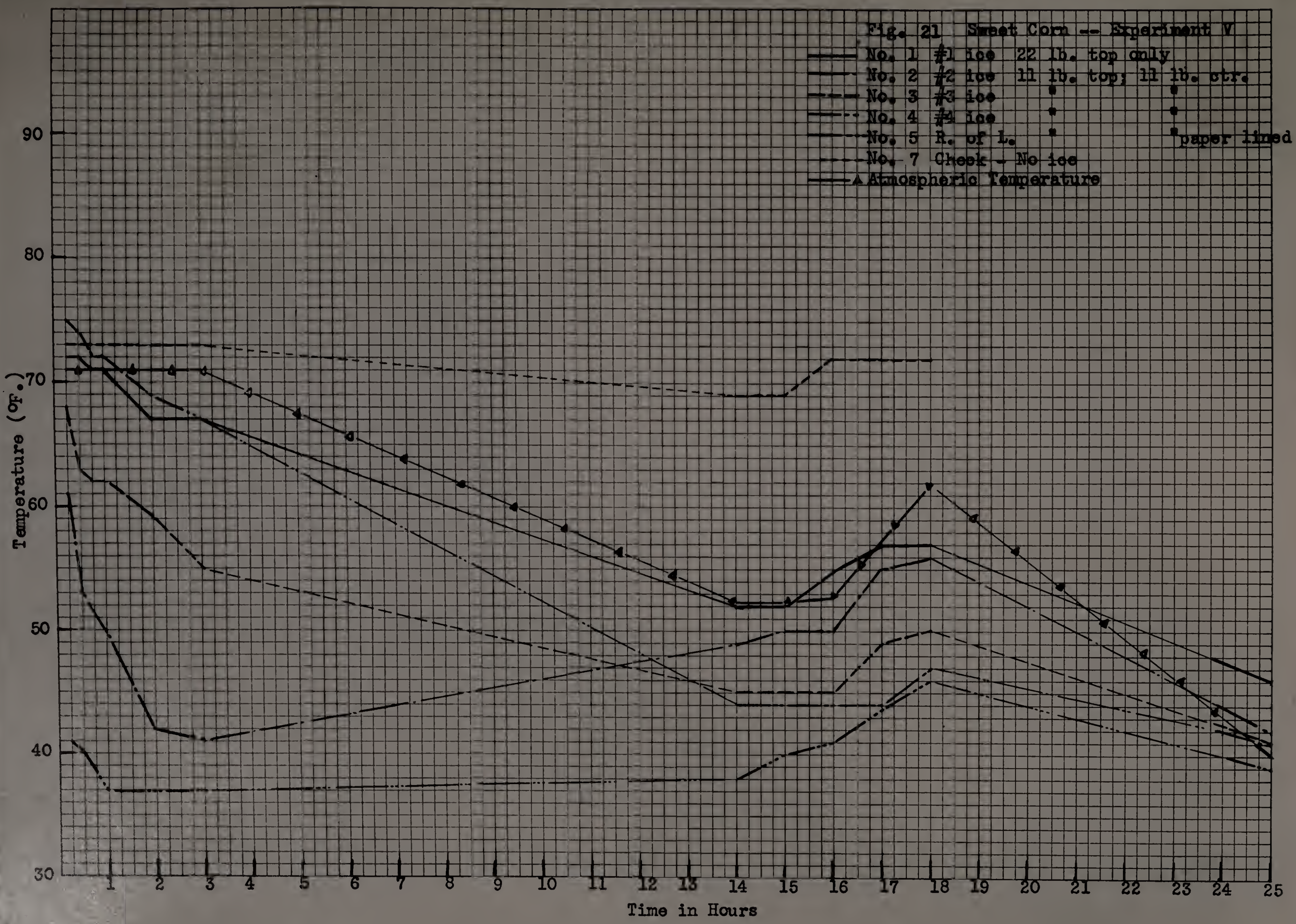


Fig. 21 Sweet Corn -- Experiment V
No. 1 #1 ice 22 lb. top only
No. 2 #2 ice 11 lb. top; 11 lb. str.
No. 3 #3 ice " "
No. 4 #4 ice " "
No. 5 R. of L. " " paper lined
No. 7 Check - No ice
Atmospheric Temperature
Temperature (°F.)
90
80
70
60
50
40
30
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Time in Hours

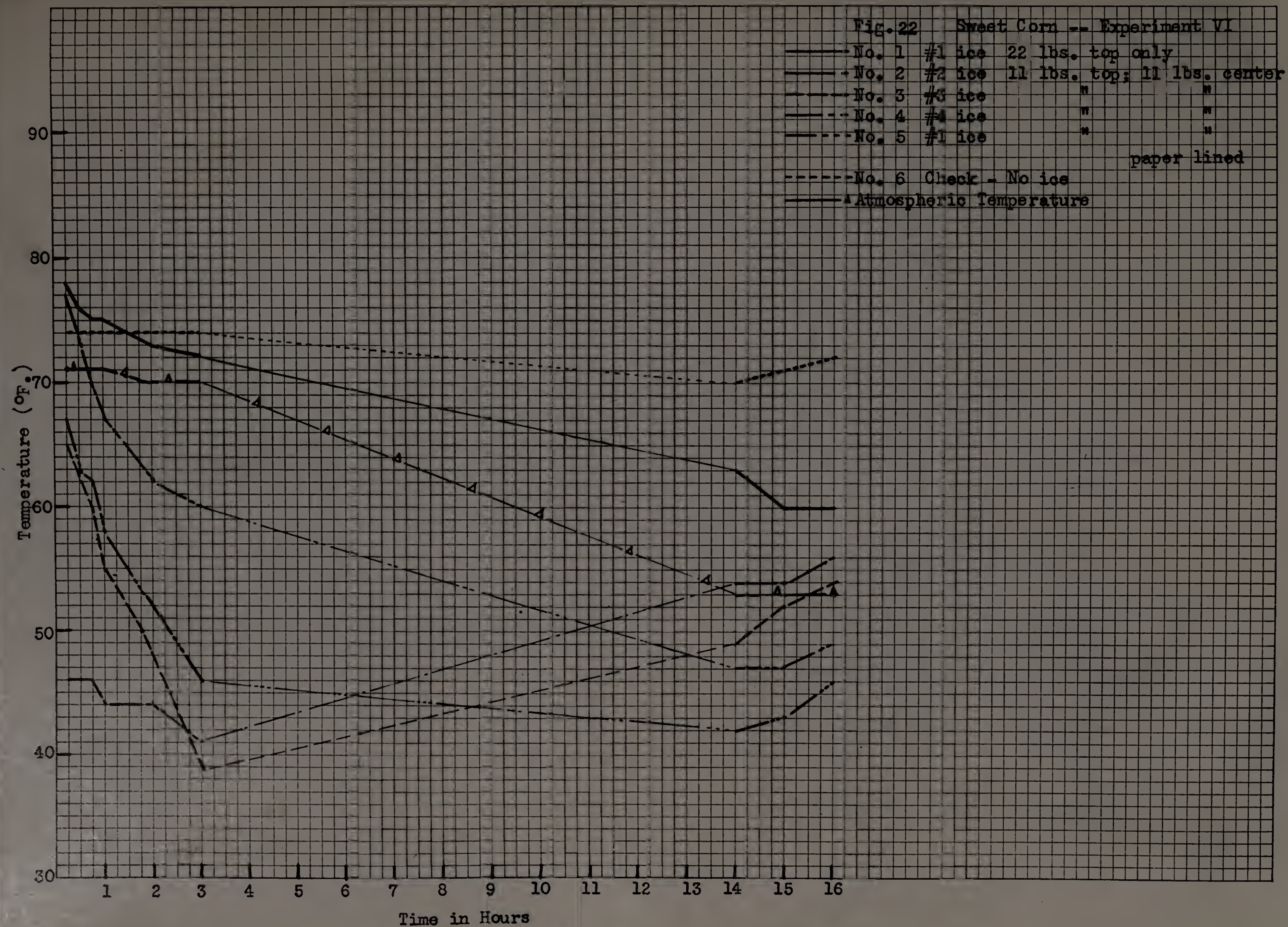


Fig. 22 Sweet Corn -- Experiment VI
No. 1 #1 ice 22 lbs. top only
No. 2 #2 ice 11 lbs. top; 11 lbs. center
No. 3 #3 ice " "
No. 4 #4 ice " "
No. 5 #1 ice " "
paper lined
No. 6 Check - No ice
Atmospheric Temperature
Temperature (°F.)
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Time in Hours

Relation of Ice Size to Speed of Lowering Package Temperature and Length of Time Refrigeration is Effective

In the discussion of each experiment definite temperature trends have been evident. It has been noted that smallest sizes of ice lowered package temperature most rapidly, but did not maintain the low temperature toward the latter part of each experiment. Large grades of ice have been described as lowering package temperature slowly, but holding temperature at a lower level than small sizes during the late hours of the experiments. This relationship has been referred to as a reverse temperature trend.

It will be observed in Table VI that one hour from the time of icing average temperature for five experiments was 40.8°F. when #1 ice was used in the package. When the next largest size, grade #2, was used, average package temperature after the first hour was 43.6°F. Thus the #1 grade maintained an average temperature 2.8°F. below #2 grade. The average temperature of #3 iced packages was 6.8°F. above the #2 packages, and temperature of #4 iced packages was 10.8°F. above containers packed with #3 ice. Thus it is noted that one hour after icing packages the smallest size of crushed ice, #1, produced an average package temperature which was 20.4°F. lower than the largest grade.

Referring to the second portion of Table VI, it may be seen that at the last hour of the five experiments packages refrigerated with #1 ice had an average temperature 3.8°F. higher than the packages with #2 ice. Similarly, containers with #2 ice had an average temperature 3.6°F. higher than containers with #3 ice. The #3 iced packs averaged 5.0°F. above the #4 iced containers. A reverse temperature relationship will be observed at the last hour of the experiments. The smallest sizes of crushed ice produced an average container temperature which was <u>12.4°F. higher</u> than the largest size.

Although the temperature data is incomplete in Table VII, a reverse temperature relationship may be observed which is very similar to that noted in Table VI. One hour from the time of icing, packages with the smallest size of crushed ice, #1, had an average temperature which was <u>23.4°F. lower</u> than packages with the largest ice size, #4. Conversely, at the last hour of experimentation, the #1 grade of crushed ice produced an average temperature which was <u>9.2°F. higher</u> than the #4 grade.

Table VI
Relation of Ice Size to Speed of Lowering Package Temperature and Time Refrigeration Was Effective
(Data Complete)

Package Temperature One Hour from Time of Icing

Crop	Carrots		Celery	Sweet Corn		Average Temperature
Experiment	I	II	II-B	I	III	
#1 ice	49°F.	36°F.	33°F.	38°F.	48°F.	40.8°F.
#2 ice	61°F.	34°F.	34°F.	40°F.	49°F.	43.6°F.
#3 ice	62°F.	44°F.	42°F.	50°F.	54°F.	50.4°F.
#4 ice	74°F.	62°F.	51°F.	56°F.	63°F.	61.2°F.

Package Temperature Last Hour of Experiment

Crop	Carrots		Celery	Sweet Corn		Average Temperature
Experiment	I	II	II-B	I	III	
#1 ice	77°F.	72°F.	58°F.	52°F.	55°F.	62.8°F.
#2 ice	72°F.	72°F.	52°F.	52°F.	47°F.	59.0°F.
#3 ice	71°F.	67°F.	49°F.	43°F.	47°F.	55.4°F.
#4 ice	68°F.	63°F.	43°F.	38°F.	40°F.	50.4°F.

Table VII
Relation of Ice Size to Speed of Lowering Package Temperature
And Time Refrigeration Was Effective
(Data Incomplete)

Package Temperature One Hour from Time of Icing

Crop	Carrots		Celery				Spinach		Sweet Corn						Average Temperature
Experiment	I	II	I-A	I-B	II-A	II-B	I	II	I	II	III	IV	V	VI	
#1 ice	49°F.	36°F.	---	---	---	33°F.	33°F.	39°F.	38°F.	36°F.	48°F.	---	---	---	39.6°F.
#2 ice	61°F.	34°F.	40°F.	49°F.	40°F.	34°F.	55°F.	---	40°F.	40°F.	49°F.	61°F.	50°F.	44°F.	45.9°F.
#3 ice	62°F.	44°F.	51°F.	45°F.	45°F.	42°F.	51°F.	62°F.	50°F.	50°F.	54°F.	63°F.	62°F.	55°F.	52.6°F.
#4 ice	74°F.	62°F.	55°F.	52°F.	53°F.	51°F.	---	82°F.	56°F.	---	63°F.	71°F.	70°F.	67°F.	63.0°F.

Package Temperature Last Hour of Experiment

Crop	Carrots		Celery				Spinach		Sweet Corn						Average Temperature
Experiment	I	II	I-A	I-B	II-A	II-B	I	II	I	II	III	IV	V	VI	
#1 ice	77°F.	72°F.	---	---	---	58°F.	---	43°F.	52°F.	43°F.	55°F.	---	---	---	57.1°F.
#2 ice	72°F.	72°F.	71°F.	70°F.	55°F.	52°F.	---	---	52°F.	41°F.	47°F.	49°F.	42°F.	56°F.	56.6°F.
#3 ice	71°F.	67°F.	62°F.	60°F.	54°F.	49°F.	---	39°F.	43°F.	36°F.	47°F.	42°F.	41°F.	54°F.	51.2°F.
#4 ice	68°F.	63°F.	59°F.	57°F.	46°F.	43°F.	---	33°F.	38°F.	---	40°F.	38°F.	41°F.	49°F.	47.9°F.

Temperature Gradients in Stacks of Iced Vegetable Packages

Most growers pack crates of a specific vegetable in a uniform manner and place approximately the same amount of ice in each container. Although packages are iced similarly, when they are stacked together on a truck, temperature varies considerably between the top and bottom layers of boxes.

The average temperatures of top, center, and bottom iced packages in stacks of vegetable crates and boxes is listed in Table VIII. It will be noted that in the top tier of packages there was only 6.6°F. difference in average temperature between the average of all corn stacks and average of all lettuce stacks. These were the extremes of average temperature of top tiers. In the bottom tier of iced packages there was found to be only 3.6°F. difference in average temperature between extremes; the higher averages being found in carrots, and the lower in celery. Thus it will be observed that average temperature differences in corresponding tiers of iced packages were slight, even though stacks of different vegetables were compared.

Average temperaturesof stacks for any one crop were found to exhibit a gradient from the top tier to the bottom tier of a stack. Highest temperatures were recorded in top tiers, intermediate temperatures in center tiers, and lowest temperatures in the bottom tiers. In his studies on refrigerator cars, Fisher (18) found similar temperature relationships between top and bottom crates of iced vegetables.

The gradient trend is found operative in celery and carrot stacks. Although data on center tier temperature is incomplete for sweet corn and lettuce, the center tier temperatures which were recorded show temperature averages which are intermediate to temperatures of top and bottom tiers.

Average temperature of all nineteen iced stacks was 52.4°F. for top tiers and 43.1°F. for bottom tiers; a difference of 9.3°F. between the two tier temperatures. The lower temperatures which were found in the bottom boxes were attributed to the dripping of ice water from the top packages into the lower packages of a stack. Probably another contributing factor which led to lower temperature in bottom tiers was the manner in which stacking reduced air circulation through the bottom containers.

Average temperatures of stacks in which packages were not iced appear in the second portion of Table VIII. A reverse temperature gradient will be noted in the average of all uniced stacks. Top tier average temperature was 71.6°F., center tier 72.2°F., and bottom tier 75.4°F. The difference in average temperature between top and bottom tiers in uniced stacks was only $3.8^{\circ}F.$ as compared with $9.3^{\circ}F.$ in the iced stacks. In the stacks of iced packages lowest average temperature was noted in bottom tiers and highest in top packages. Conversely, in stacks of uniced packages, top boxes had slightly lower temperatures than bottom boxes.

Table VIII
Average Temperature of Stacks of Vegetable Packages

(Packages Iced - Each Temperature Average of 15 Readings)

Crop	Date	Stack -- Number of Packages High	Top Tier	Center Tier	Bottom Tier
Celery	8/11/47	6	57.1°F.	41.9°F.	43.4°F.
"	8/12/47	8	56.4	52.1	40.4
"	8/19/48	8	50.6	44.8	38.8
"	8/19/48	8	58.5	48.3	47.0
"	9/13/48	6	41.3	41.5	38.7
Average of all celery stacks			54.6°F.	46.2°F.	41.6°F.
Sweet Corn	8/19/47	5	65.3°F.	41.7°F.	34.1°F.
" "	8/20/47	5	38.9	35.2	34.5
" "	8/28/47	5	40.2	--	38.3
" "	8/28/47	5	52.7	--	33.5
" "	9/2/48	5	60.3	56.5	52.8
Average of all corn stacks			54.6°F.	--	43.7°F.
Lettuce	7/26/48	5	54.0°F.	--	44.9°F.
"	7/29/48	5	60.5	53.0	48.5
"	8/8/48	5	44.1	41.3	38.0
"	8/9/48	5	43.3	--	42.0
"	8/10/48	5	42.0	41.5	37.5
Average of all lettuce stacks			48.0°F.	--	42.4°F.
Carrots	8/21/48	5	49.4°F.	43.4°F.	38.6°F.
"	8/25/48	5	55.2	50.8	47.6
"	8/26/48	5	53.4	48.6	46.0
"	9/2/48	4	50.7	49.5	48.2
Average of carrot stacks			52.1°F.	48.1°F.	45.2°F.
Average of all iced stacks			52.4°F.	--	43.1°F.

(Packages Not Iced - Each Temperature Average of 15 Readings)

Crop	Date	Stack -- Number of Packages High	Top Tier	Center Tier	Bottom Tier
Celery	9/13/48	6	74.1°F.	75.0°F.	77.4°F.
Spinach	9/9/48	5	61.8	62.3	64.0
Spinach	9/10/48	5	73.3	75.8	78.3
Sweet Corn	9/2/48	5	60.8	60.8	68.3
Sweet Corn	8/27/48	5	89.5	88.3	90.5
Lettuce	7/28/48	5	72.3	74.5	77.0
Average of all uniced stacks			71.6°F.	72.2°F.	75.4°F.

Tap or Wash Water as a Cooling Medium

Many vegetable growers have maintained that tap water used in washing vegetables has refrigerating value. Pyke and Allison (51) found wash water to range from 55° to 60°F. Truscott (64) stated that temperature of spring water was seldom below 40°F. Zink (69) found that packing shed wash water averaged 70°F.

Temperatures of tap water were taken in seven different packing houses and appear in Table IX. The lowest average temperature recorded was 57.0°F. and the highest average temperature was 76.2°F. The average of all tap water temperatures was 67.3°F. From this it may be concluded that tap or wash water used in the packing houses where experiments were conducted, had very little value as a cooling medium.

Table IX
Tap Water Temperature in Packing Sheds

(Each Temperature is the Average of 10 Readings)

Date	Place	Temperature
7/15/47	University of Mass., packing shed	69.4°F.
7/11/47	University of Mass., packing shed	76.2°F.
7/17/47	University of Mass., packing shed	74.0°F.
8/7/47	University of Mass., packing shed	74.4°F.
8/11/47	Whitmore and Richardson Farm, Sunderland, Mass.	65.1°F.
8/12/47	Whitmore and Richardson Farm, Sunderland, Mass.	68.6°F.
8/16/47	Whitmore and Richardson Farm, Sunderland, Mass.	64.2°F.
8/26/47	Doty Gardens, West Springfield, Mass.	68.9°F.
8/27/47	Albert Christopher Farm, Agawam, Mass.	70.4°F.
8/28/47	Albert Christopher Farm, Agawam, Mass.	69.0°F.
9/9/47	De Vincent Bros. Farm, Waltham, Mass.	68.1°F.
9/10/47	De Vincent Bros. Farm, Waltham, Mass.	65.4°F.
7/26/48	Herbert Holmes Farm, West Bridgewater, Mass.	68.3°F.
7/27/48	Herbert Holmes Farm, West Bridgewater, Mass.	67.5°F.
7/28/48	Herbert Holmes Farm, West Bridgewater, Mass.	65.0°F.
7/29/48	Herbert Holmes Farm, West Bridgewater, Mass.	68.3°F.

Table IX (Continued)
Tap Water Temperature in Packing Sheds

(Each Temperature is the Average of 10 Readings)

Date	Place	Temperature
8/6/48	Herbert Holmes Farm, West Bridgewater, Mass.	66.0°F.
8/9/48	Herbert Holmes Farm, West Bridgewater, Mass.	68.1°F.
8/10/48	Herbert Holmes Farm, West Bridgewater, Mass.	67.7°F.
8/19/48	Whitmore and Richardson Farm, Sunderland, Mass.	57.0°F.
8/25/48	Doty Gardens, West Springfield, Mass.	69.4°F.
8/26/48	Doty Gardens, West Springfield, Mass.	66.9°F.
9/8/48	De Vincent Bros. Farm, Waltham, Mass.	64.2°F.
9/13/48	Andy Boy Packing Plant, West Concord, Mass.	59.4°F.
9/14/48	Andy Boy Packing Plant, West Concord, Mass.	61.3°F.

Average of all tap water temperatures --- 67.3°F.

Precooling Lettuce with Iced Water

(The designs of hydrocoolers are described under MATERIALS AND METHODS).

Four experiments were conducted on an overhead-drain hydrocooler. This work was accomplished at Veg-Acre Farms, Forestdale, Massachusetts on August 2 and 3, 1948. Lettuce was cut, trimmed, and packed in the field.

It will be noted in Table X that average temperature of the top layer of heads after being in the hydrocooler for three minutes was 44.7°F. for all experiments. Average temperature of the bottom layer of heads was 60.0°F. for all experiments. From this it will be observed that iced water falling in a rain-like sheet precooled the top layer of heads an average of 15.3°F. lower than the bottom layer.

Four experiments were conducted on an immersion hydrocooler. Work was done at the farm of Herbert A. Holmes, West Bridgewater, Massachusetts on August 10, 1948. Methods of field cutting and handling were the same as those used on Veg-Acre Farms.

In Table X it will be observed that average temperature of the top layer of heads is 41.7°F. for all experiments and the bottom layer is 44.0°F. The average temperature of the top layer is only 2.3°F. lower than the bottom layer as compared with the 15.3°F. differential found in the overhead-drain hydrocooler.

In comparing efficiencies of the two coolers under conditions of these experiments, it will be observed that the immersion hydrocooler accomplished a more efficient job of precooling than did the overhead-drain hydrocooler. In the immersion hydrocooler, crates of lettuce are totally submerged in iced water. The water not only surrounds each head, but penetrates the open spaces between leaves. Under these conditions, the cooling medium is in direct contact with the heads. Conversely, in the overhead-drain hydrocooler, iced water comes in contact primarily with the top layer of heads, and does not have full access to the bottom layer. As a result, the bottom layer of heads does not receive full benefit of refrigeration from the iced water and temperature is not lowered appreciably.

Precooling lettuce with iced water is preferred to cooling with cold air. Platenius (48) found it necessary to store lettuce in a cold room for 30 hours in order to lower temperature of heads to 40°F. The immersion hydrocooler studied in the current project lowered temperature of heads to approximately 40°F. in a period of three minutes.

Table X
Refrigerating Efficiency of an Overhead-Drain Hydrocooler and an Immersion Hydrocooler In Precooling Boxes of Lettuce

Average temperature of top and center layers of lettuce heads after three minutes in an overhead-drain hydrocooler (Each temperature is the average of 20 readings).

8/2/48	Top layer of heads	Bottom layer of heads
Experiment I	44.0°F.	62.7°F.
Experiment II	43.8°F.	65.2°F.
8/3/48		
Experiment III	45.1°F.	57.7°F.
Experiment IV	46.0°F.	58.1°F.
Average of all Experiments ---	44.7°F.	60.0°F.

Average temperature of top and center layers of lettuce heads after three minutes in an immersion hydrocooler (Each temperature is the average of 20 readings).

8/10/48	Top layer of heads	Bottom layer of heads
Experiment I	42.5°F.	42.3°F.
Experiment II	40.8°F.	41.8°F.
Experiment III	41.6°F.	44.0°F.
Experiment IV	42.5°F.	47.0°F.
Average of all Experiments ---	41.7°F.	44.0°F.

SUMMARY AND CONCLUSIONS

Experiments are described in which five different grades of crushed ice were placed in vegetable packages. Varying quantities of ice were used in containers. This was done to determine the optimum amounts of ice necessary to refrigerate specific vegetables during short hauls to market. A check crate which remained uniced was included in each experiment.

Carrots, celery, lettuce, spinach, and sweet corn were packed in containers which are commonly used for these crops in local Massachusetts markets.

Package temperature history was recorded at eight farms, in three wholesale markets, and in six retail stores. Packages moved through the normal market channels. The speed with which package temperature was reduced was noted, and the period of time that refrigeration was effective was also recorded.

Lettuce precooling experiments were conducted on an over-head drain hydrocooler and an immersion hydrocooler. Refrigerating efficiencies of these two types of precoolers are discussed.

On the basis of experimental data, it was found that under market conditions, ice grades #1 (snow) and #2 (fine) lowered package temperature most rapidly. In five experiments, one hour from the time packages were filled, average temperature in containers iced with the #1 grade was found to be 20.4°F. lower than average temperature of packs iced with #4 grade. The small sizes of crushed ice did not, however, maintain refrigeration as long as the large sizes. At the last hour reading of five experiments, average temperature in packages iced with #1 grade was found to be 12.4°F. higher than average temperature of crates and boxes iced with the #4 grade. Thus small sizes of crushed ice lowered package temperature most rapidly but did not maintain the lowered temperature, while large sizes of crushed ice lowered temperature slowly, but held the temperature at a lower level during the late hours of the experiments. This relationship has been termed a <u>reverse temperature trend</u>.

Snow ice was found to pack into crevices around vegetables thereby supplying refrigeration directly to the product. There was a distinct tendency for this grade of ice to cake together.

If several packages were stacked vertically, pressure exerted on the bottom crates was found to push ice grades #3 and #4 into tender commodities such as celery and lettuce. This resulted in bruising and pitting damage to the product. These two grades of ice were found to slide out of open-slatted crates.

The run-of-the-line grade of crushed ice contained small pieces of ice which melted rapidly and lowered temperature quickly. It had enough large chunks to maintain lowered temperature during short hauls to market (twenty-four hours or less). Large pieces of ice in this grade imparted the same disadvantages as grades #3 and #4.

It was found that placing ice in the center and top of packages depressed temperature more and maintained refrigeration for a longer period of time than placement of the same amount of ice only on the top of vegetables in the containers.

Temperature in paper lined crates dropped more rapidly and remained at a lower level than temperature of unlined crates. It was concluded that this was undoubtedly the result of reducing air circulation through the crates. Paper liners were found to enhance the appearance of a package and keep the vegetables clean. An additional advantage of using paper liners was found in the open-slatted Bruce crate. With this type of package, liners kept crushed ice from sliding out through openings between slats.

Growers pack crates of a specific vegetable uniformly and place approximately the same amount of ice in each container. Although packages were prepared similarly, when they were stacked together on a truck, temperature varied considerably between top and bottom tiers of boxes. Average temperature of nineteen iced stacks was 52.4°F. for top tiers, and 43.1°F. for bottom tiers. The temperature differential of these stacks was 9.3°F. Thus a temperature gradient was established from top to bottom tiers of packages; top tiers having higher temperatures than bottom tiers. This gradient was attributed to the dripping of ice water from the top packages into the lower packages of a stack. Another contributing factor leading to lower temperatures in the bottom tiers was the manner in which stacking reduced air circulation through the bottom containers.

Unrefrigerated wash water and tap water in packing sheds was found to have practically no value as a cooling medium. In the two seasons of work, the lowest tap water temperature recorded was 57.0°F. Average temperature of wash water recorded at seven different vegetable farms was 67.3°F.

Experiments were conducted to determine the refrigerating efficiencies of an overhead-drain hydrocooler and an immersion hydrocooler. Two dozen lettuce heads were packed to a box. Boxes were run through both hydrocoolers for a period of three minutes. In the overhead-drain hydrocooler experiments, average temperature of the top layer of heads was 44.7°F., and average temperature of the bottom layer was 60.0°F. Hence there was a differential of 15.3°F. between average temperature of top and bottom layers of lettuce heads. Although the top layer of heads was well precooled, the bottom layer received only a small amount of refrigeration. With the immersion hydro-cooler, average temperature of the top layer of heads was 41.7°F., and average temperature of the bottom layer was 44.0°F. The temperature differential between top and bottom layers was only 2.3°F.

It was concluded that under the conditions of this experiment, refrigeration was applied more efficiently and uniformly to lettuce in the immersion hydrocooler than in the overhead-drain hydrocooler.

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A P P E N D I X

Table A — CARROTS, Experiment I, 1948

Place and Time of Experiment	Time from Icing	No. 1 crate #1 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 2 crate #2 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 3 crate #3 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 4 crate #4 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 5 crate Check No Ice	Atmospheric Temperature
8/25 Packing Shed							
3:00 p.m.	15 min.	62°F.	68°F.	76°F.	76°F.	78°F.	88°F.
	30 min.	55°F.	64°F.	75°F.	76°F.	78°F.	89°F.
	45 min.	51°F.	64°F.	74°F.	75°F.	78°F.	89°F.
4:00 p.m.	1 hour	49°F.	61°F.	62°F.	74°F.	78°F.	89°F.
5:00 p.m.	2 hours	42°F.	52°F.	60°F.	66°F.	79°F.	93°F.
8/26 Wholesale Market							
5:00 a.m.	14 hours	63°F.	70°F.	57°F.	45°F.	80°F.	75°F.
6:00 a.m.	15 hours	64°F.	70°F.	57°F.	48°F.	80°F.	76°F.
7:00 a.m.	16 hours	73°F.	70°F.	57°F.	49°F.	80°F.	76°F.
8:00 a.m.	17 hours	73°F.	70°F.	57°F.	52°F.	80°F.	81°F.
9:00 a.m.	18 hours	73°F.	71°F.	63°F.	52°F.	80°F.	85°F.
Crates Carried Back to Packing Shed							
4:00 p.m.	25 hours	77°F.	72°F.	71°F.	68°F.	83°F.	95°F.

Table B — CARROTS, Experiment II, 1948

Place and Time of Experiment	Time from Icing	No. 1 crate #1 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 2 crate #2 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 3 crate #3 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 4 crate #4 ice 7 lb. top; 7 lb. ctr. 7 lb. bottom	No. 5 crate Check No Ice	Atmospheric Temperature
8/26 Packing Shed							
10:00 a.m.	15 min.	42°F.	38°F.	57°F.	67°F.	78°F.	81°F.
	30 min.	36°F.	34°F.	52°F.	64°F.	78°F.	81°F.
	45 min.	36°F.	34°F.	48°F.	62°F.	78°F.	81°F.
11:00 a.m.	1 hour	36°F.	34°F.	44°F.	62°F.	78°F.	81°F.
12:00 M	2 hours	35°F.	41°F.	41°F.	58°F.	78°F.	83°F.
1:00 p.m.	3 hours	35°F.	42°F.	40°F.	56°F.	79°F.	84°F.
8/27 Wholesale Market							
4:00 a.m.	18 hours	71°F.	71°F.	66°F.	61°F.	79°F.	80°F.
5:00 a.m.	19 hours	71°F.	71°F.	67°F.	62°F.	80°F.	80°F.
6:00 a.m.	20 hours	72°F.	72°F.	67°F.	63°F.	81°F.	80°F.

Table C -- CELERY, Experiment I-A, 1947

Time and Place of Experiment	Time from Icing	A-1 box R.ofL. ice 3 lb.top; 3 lb. ctr.	A-2 box #2 ice 3 lb.top; 3 lb.ctr.	A-3 box #3 ice 3 lb.top; 3 lb.ctr.	A-4 box #4 ice 3 lb.top; 3 lb.ctr.	Atmospheric Temperature
8/12 11:00 a.m.	15 min.	54°F.	52°F.	52°F.	59°F.	68°F.
Packing Shed	30 min.	50°F.	49°F.	51°F.	59°F.	69°F.
	45 min.	41°F.	47°F.	51°F.	57°F.	70°F.
12:00 M	1 hour	38°F.	40°F.	51°F.	55°F.	72°F.
1:00 p.m.	2 hours	35°F.	38°F.	41°F.	52°F.	79°F.
2:00 p.m.	3 hours	38°F.	40°F.	45°F.	51°F.	85°F.
3:00 p.m.	4 hours	40°F.	41°F.	49°F.	51°F.	86°F.
4:00 p.m.	5 hours	41°F.	43°F.	51°F.	54°F.	88°F.
5:00 p.m.	6 hours	43°F.	47°F.	53°F.	56°F.	88°F.
6:00 p.m.	7 hours	48°F.	49°F.	56°F.	59°F.	88°F.
7:00 p.m.	8 hours	51°F.	49°F.	57°F.	59°F.	88°F.
8:00 p.m.	9 hours	56°F.	55°F.	59°F.	59°F.	83°F.
9:00 p.m.	10 hours	60°F.	59°F.	60°F.	60°F.	81°F.
8/13 4:00 a.m.	17 hours	60°F.	66°F.	61°F.	58°F.	
On Truck 5:00 a.m.	18 hours	62°F.	69°F.	61°F.	58°F.	
Wholesale Market	19 hours	66°F.	70°F.	62°F.	58°F.	No
7:00 a.m.	20 hours	67°F.	71°F.	62°F.	59°F.	Data
8:00 a.m. Retail Store	21 hours	67°F.	71°F.	62°F.	59°F.	

Table D -- CELERY, Experiment I-B, 1947

Time and Place of Experiment	Time from Icing	B-1 box R.ofL. ice 5 lb.top; 5 lb.ctr.	B-2 box #2 ice 5 lb.top; 5 lb.ctr.	B-3 box #3 ice 5 lb.top; 5 lb.ctr.	B-4 box #4 ice 5 lb.top; 5 lb.ctr.	Atmospheric Temperature
8/12						
11:00 a.m. Packing Shed	15 min.	52°F.	59°F.	52°F.	59°F.	68°F.
	30 min.	40°F.	52°F.	50°F.	58°F.	69°F.
	45 min.	38°F.	50°F.	46°F.	56°F.	71°F.
12:00 M	1 hour	38°F.	49°F.	45°F.	52°F.	72°F.
1:00 p.m.	2 hours	38°F.	40°F.	41°F.	49°F.	79°F.
2:00 p.m.	3 hours	36°F.	36°F.	43°F.	43°F.	85°F.
3:00 p.m.	4 hours	36°F.	34°F.	47°F.	44°F.	86°F.
4:00 p.m.	5 hours	40°F.	36°F.	49°F.	48°F.	88°F.
5:00 p.m.	6 hours	40°F.	37°F.	50°F.	52°F.	88°F.
6:00 p.m.	7 hours	47°F.	42°F.	54°F.	57°F.	88°F.
7:00 p.m.	8 hours	47°F.	43°F.	55°F.	57°F.	88°F.
8:00 p.m.	9 hours	54°F.	44°F.	55°F.	57°F.	83°F.
9:00 p.m.	10 hours	58°F.	45°F.	55°F.	58°F.	81°F.
8/13						
4:00 a.m. On Truck	17 hours	54°F.	62°F.	58°F.	55°F.	No Data
5:00 a.m. Wholesale Market	18 hours	55°F.	64°F.	59°F.	55°F.	
	19 hours	56°F.	68°F.	59°F.	56°F.	
7:00 a.m.	20 hours	58°F.	70°F.	59°F.	56°F.	
8:00 a.m. Retail Store	21 hours	58°F.	70°F.	60°F.	57°F.	

Table E -- CELERY, Experiment II-A, 1948

Place and Time of Experiment	Time from Icing	A-1 box R.ofL. ice 3 lb.top; 3 lb.ctr.	A-2 box #2 ice 3 lb.top; 3 lb.ctr.	A-3 box #3 ice 3 lb.top; 3 lb.ctr.	A-4 box #4 ice 3 lb.top; 3 lb.ctr.	Atmospheric Temperature
8/19 Packing Shed						
2:00 p.m.	15 min.	33°F.	43°F.	51°F.	61°F.	64°F.
	30 min.	33°F.	42°F.	49°F.	58°F.	64°F.
	45 min.	33°F.	41°F.	46°F.	55°F.	64°F.
3:00 p.m.	1 hour	33°F.	40°F.	45°F.	53°F.	64°F.
4:00 p.m.	2 hours	33°F.	37°F.	42°F.	51°F.	64°F.
5:00 p.m.	3 hours	33°F.	33°F.	41°F.	48°F.	64°F.
6:00 p.m.	4 hours	35°F.	33°F.	42°F.	47°F.	64°F.
8/20 On Truck						
2:00 a.m.	12 hours	48°F.	50°F.	43°F.	41°F.	64°F.
Wholesale Market						
4:00 a.m.	14 hours	51°F.	50°F.	45°F.	42°F.	64°F.
5:00 a.m.	15 hours	52°F.	50°F.	46°F.	43°F.	65°F.
6:00 a.m.	16 hours	53°F.	51°F.	47°F.	44°F.	68°F.
7:00 a.m.	17 hours	55°F.	52°F.	48°F.	45°F.	68°F.
8:00 a.m.	18 hours	58°F.	52°F.	50°F.	45°F.	71°F.
9:00 a.m.	19 hours	59°F.	53°F.	52°F.	45°F.	72°F.
10:00 a.m.	20 hours	61°F.	55°F.	54°F.	46°F.	74°F.

Table F -- CELERY, Experiment II-B, 1948

Place and Time of Experiment	Time from Icing	B-1 box #1 ice 5 lb.top; 5 lb.ctr.	B-2 box #2 ice 5 lb.top; 5 lb.ctr.	B-3 box #3 ice 5 lb.top; 5 lb.ctr.	B-4 box #4 ice 5 lb.top; 5 lb.ctr.	Atmospheric Temperature
8/19 Packing Shed 2:00 p.m.	15 min.	33°F.	34°F.	51°F.	53°F.	64°F.
	30 min.	33°F.	34°F.	47°F.	52°F.	64°F.
	45 min.	33°F.	34°F.	43°F.	52°F.	64°F.
3:00 p.m.	1 hour	33°F.	34°F.	42°F.	51°F.	64°F.
4:00 p.m.	2 hours	33°F.	33°F.	40°F.	50°F.	64°F.
5:00 p.m.	3 hours	33°F.	33°F.	39°F.	43°F.	64°F.
6:00 p.m.	4 hours	33°F.	33°F.	39°F.	41°F.	64°F.
8/20 On Truck 2:00 a.m.	12 hours	46°F.	43°F.	43°F.	40°F.	64°F.
Wholesale Market 4:00 a.m.	14 hours	48°F.	49°F.	43°F.	41°F.	64°F.
5:00 a.m.	15 hours	52°F.	49°F.	43°F.	41°F.	65°F.
6:00 a.m.	16 hours	53°F.	49°F.	43°F.	41°F.	68°F.
7:00 a.m.	17 hours	54°F.	50°F.	44°F.	42°F.	68°F.
8:00 a.m.	18 hours	56°F.	51°F.	46°F.	42°F.	71°F.
9:00 a.m.	19 hours	57°F.	52°F.	47°F.	43°F.	72°F.
10:00 a.m.	20 hours	58°F.	52°F.	49°F.	43°F.	74°F.

Table G -- LETTUCE, Experiment I, 1948

Place and Time of Experiment	Time from Icing	No.1 box #1 ice 20 lbs. top only	No.2 box #1 ice 10 lbs. top; 10 lbs. ctr.	No.3 box R. of L. Ice 20 lbs. top only	No. 4 box R.ofL.ice Paper Lined 10 lb.top. 10 lb.ctr.	No. 5 Box Check No ice	Atmospheric Temperature
7/26 Packing Shed							
3:00 p.m.	15 min.	55°F.	48°F.	64°F.	42°F.	68°F.	73°F.
	30 min.	53°F.	45°F.	62°F.	40°F.	68°F.	74°F.
	45 min.	51°F.	45°F.	60°F.	38°F.	68°F.	75°F.
4:00 p.m.	1 hour	51°F.	44°F.	60°F.	37°F.	68°F.	76°F.
5:00 p.m.	2 hours	53°F.	44°F.	60°F.	36°F.	68°F.	74°F.
6:00 p.m.	3 hours	55°F.	42°F.	60°F.	36°F.	68°F.	74°F.
7:00 p.m.	4 hours	55°F.	45°F.	60°F.	36°F.	68°F.	74°F.
7/27 Wholesale Market							
6:00 a.m.	15 hours	68°F.	65°F.	69°F.	37°F.	69°F.	68°F.
9:00 a.m.	18 hours	70°F.	67°F.	70°F.	40°F.	73°F.	74°F.

Table H -- LETTUCE, Experiment II, 1948

Place and Time of Experiment	Time from Icing	No.1 box #1 ice 20 lbs. top only	No.2 box #1 ice 10 lbs. top; 10 lbs. ctr.	No.3 box R. of L. Ice 20 lbs. top only	No. 4 box #1 ice Paper Lined 10 lb.top; 10 lb.ctr.	No. 5 Box Check No ice	Atmospheric Temperature
7/27 Packing Shed							
2:00 p.m.	15 min.	72°F.	72°F.	73°F.	44°F.	72°F.	75°F.
	30 min.	70°F.	71°F.	72°F.	43°F.	72°F.	75°F.
	45 min.	70°F.	70°F.	72°F.	42°F.	72°F.	75°F.
3:00 p.m.	1 hour	68°F.	70°F.	70°F.	40°F.	72°F.	75°F.
4:00 p.m.	2 hours	55°F.	52°F.	68°F.	34°F.	73°F.	74°F.
5:00 p.m.	3 hours	53°F.	50°F.	63°F.	34°F.	73°F.	74°F.
6:00 p.m.	4 hours	46°F.	48°F.	62°F.	34°F.	73°F.	73°F.
7/28 Wholesale Market							
5:00 a.m.	15 hours	69°F.	58°F.	68°F.	38°F.	75°F.	72°F.
8:00 a.m.	18 hours	70°F.	62°F.	70°F.	40°F.	74°F.	73°F.
9:00 a.m.	19 hours	70°F.	62°F.	70°F.	40°F.	70°F.	74°F.

Table I -- LETTUCE, Experiment III, 1948

Place and Time of Experiment	Time from Icing	No. 1 box R.ofL. ice 20 lbs. top only	No. 2 box R.ofL. ice 10 lbs.top; 10 lbs.ctr.	No. 3 box R.ofL. ice Paper lined 10 lbs.top; 10 lbs.ctr.	No. 4 Box Check No ice	Atmospheric Temperature
7/28 Packing Shed						
3:00 p.m.	15 min.	69°F.	46°F.	43°F.	74°F.	76°F.
	30 min.	68°F.	43°F.	42°F.	74°F.	76°F.
	45 min.	68°F.	43°F.	40°F.	74°F.	76°F.
4:00 p.m.	1 hour	68°F.	43°F.	38°F.	74°F.	76°F.
5:00 p.m.	2 hours	65°F.	43°F.	35°F.	72°F.	76°F.
6:00 p.m.	3 hours	63°F.	41°F.	34°F.	72°F.	75°F.
7:00 p.m.	4 hours	60°F.	40°F.	34°F.	70°F.	74°F.
7/29 Brockton Market						
6:00 a.m.	15 hours	61°F.	52°F.	33°F.	68°F.	68°F.
A.&P. Store						
8:00 a.m.	17 hours	62°F.	53°F.	46°F.	69°F.	70°F.
9:00 a.m.	18 hours	64°F.	55°F.	48°F.	69°F.	72°F.
A.&P. Store						
3:00 p.m.	24 hours	Used on Counter	68°F.	50°F.	71°F.	79°F.

Table J -- LETTUCE, Experiment IV, 1948

Place and Time of Experiment	Time from Icing	No.1 box #1 ice 20 lbs. top only	No.2 box #1 ice 10 lbs. top; 10 lbs. ctr.	No.3 box R. of L. Ice 20 lbs. top only	No. 4 box #1 ice Paper Lined 10 lb.top; 10 lb.ctr.	No. 5 Box Check No ice	Atmospheric Temperature
7/29 Packing Shed							
3:00 p.m.	15 min.	69°F.	68°F.	67°F.	46°F.	72°F.	80°F.
	30 min.	67°F.	59°F.	65°F.	34°F.	72°F.	80°F.
	45 min.	64°F.	50°F.	62°F.	34°F.	72°F.	79°F.
4:00 p.m.	1 hour	64°F.	50°F.	60°F.	33°F.	72°F.	78°F.
5:00 p.m.	2 hours	63°F.	50°F.	60°F.	33°F.	72°F.	77°F.
6:00 p.m.	3 hours	57°F.	50°F.	60°F.	33°F.	71°F.	75°F.
7:00 p.m.	4 hours	56°F.	49°F.	59°F.	33°F.	71°F.	74°F.
7/30 Wholesale Market							
6:00 a.m.	15 hours	41°F.	45°F.	60°F.	34°F.	60°F.	67°F.
A.&P. Store							
8:00 a.m.	17 hours	52°F.	48°F.	61°F.	35°F.	60°F.	68°F.
Left in Sun							
9:00 a.m.	18 hours	61°F.	51°F.	61°F.	47°F.	60°F.	85°F.

Table K -- LETTUCE, Experiment V, 1948

Place and Time of Experiment	Time from Icing	No. 1 box R.ofL. ice 20 lbs. Top only	No. 2 box R.ofL. ice 10 lbs.top; 10 lbs.ctr.	No. 3 box R.ofL. ice Paper lined 10 lbs.top; 10 lbs.ctr.	No. 4 Box Check No ice	Atmospheric Temperature
8/4 Packing Shed						
2:00 p.m.	15 min.	72°F.	63°F.	38°F.	73°F.	73°F.
	30 min.	72°F.	60°F.	38°F.	73°F.	73°F.
	45 min.	72°F.	57°F.	38°F.	73°F.	73°F.
3:00 p.m.	1 hour	62°F.	55°F.	37°F.	73°F.	73°F.
4:00 p.m.	2 hours	61°F.	48°F.	33°F.	74°F.	73°F.
5:00 p.m.	3 hours	60°F.	46°F.	33°F.	73°F.	74°F.
8/5 Wholesale Market						
5:00 a.m.	15 hours	55°F.	37°F.	36°F.	64°F.	66°F.
6:00 a.m.	16 hours	58°F.	41°F.	36°F.	65°F.	66°F.
7:00 a.m.	17 hours	59°F.	45°F.	37°F.	67°F.	66°F.
A.&P. Store						
8:00 a.m.	18 hours	Lost in Transit	48°F.	45°F.	67°F.	69°F.

Table L -- LETTUCE, Experiment VI, 1948

Place and Time of Experiment	Time from Icing	No. 1 box #1 ice 20 lbs. Top only	No. 2 box R.ofL. ice 20 lbs. Top only	No. 3 box R.ofL. ice 10 lbs.top; 10 lbs.ctr.	No. 4 Box Check No ice	Atmospheric Temperature
8/5 Packing Shed 3:00 p.m.	15 min.	68°F.	68°F.	64°F.	69°F.	73°F.
	30 min.	62°F.	61°F.	58°F.	69°F.	73°F.
	45 min.	60°F.	56°F.	55°F.	69°F.	72°F.
4:00 p.m.	1 hour	55°F.	54°F.	50°F.	69°F.	72°F.
5:00 p.m.	2 hours	52°F.	54°F.	48°F.	67°F.	72°F.
6:00 p.m.	3 hours	50°F.	54°F.	46°F.	66°F.	70°F.
8/6 Wholesale Market 6:00 a.m.	15 hours	45°F.	41°F.	40°F.	60°F.	66°F.
7:00 a.m.	16 hours	47°F.	42°F.	42°F.	60°F.	66°F.
A.&P. Store 8:00 a.m.	17 hours	48°F.	42°F.	42°F.	60°F.	68°F.

Table M -- SPINACH, Experiment I, 1947

Lot A

4 Hours in Packing Shed

Place and Time of Experiment	Time from Icing	No. 1 box #1 ice $3\frac{1}{2}$lb.top; $3\frac{1}{2}$lb.ctr.	No. 2 box #2 ice $3\frac{1}{2}$lb.top; $3\frac{1}{2}$lb.ctr.	No. 3 box #3 ice $3\frac{1}{2}$lb.top; $3\frac{1}{2}$lb.ctr.	No. 4 box Check No ice
9/10 Packing Shed 1:00 p.m.	15 min.	45°F.	68°F.	51°F.	70°F.
	30 min.	37°F.	61°F.	51°F.	70°F.
	45 min.	33°F.	58°F.	51°F.	70°F.
	1 hour	33°F.	55°F.	51°F.	70°F.
	2 hours	33°F.	48°F.	45°F.	71°F.
	3 hours	33°F.	40°F.	45°F.	73°F.
	4 hours	33°F.	40°F.	43°F.	74°F.
9/11 In Cold Room 6:00 a.m.	17 hours	33°F.	33°F.	33°F.	68°F.

Lot B

Directly into 40°F. Cooler

Place and Time of Experiment	Time from Icing	No. 1 box #1 ice $3\frac{1}{2}$lb.top; $3\frac{1}{2}$lb.ctr.	No. 2 box #2 ice $3\frac{1}{2}$ lb.top; $3\frac{1}{2}$ lb.ctr.	No. 3 box #3 ice $3\frac{1}{2}$lb.top; $3\frac{1}{2}$lb.ctr.	Atmospheric Temperature
9/10 Packing Shed 1:00 p.m.	15 min.	33°F.	33°F.	65°F.	80°F.
	30 min.	33°F.	33°F.	52°F.	80°F.
	45 min.	33°F.	33°F.	50°F.	80°F.
	1 hour	33°F.	33°F.	47°F.	80°F.
	2 hours	33°F.	33°F.	41°F.	80°F.
	3 hours	33°F.	33°F.	41°F.	78°F.
	4 hours	33°F.	33°F.	40°F.	76°F.
9/11 In Cold Room 6:00 a.m.	17 hours	33°F.	33°F.	33°F.	67°F.

Table N -- SPINACH, Experiment II, 1948

Place and Time of Experiment	Time from Icing	No. 1 box #1 ice 6 lb.top; 6 lb.ctr.	No. 2 box #3 ice 6 lb.top; 6 lb.ctr.	No. 3 box #4 ice 6 lb.top; 6 lb.ctr.	No. 4 box Check No Ice	Atmospheric Temperature
9/8 Packing Shed						
3:00 p.m.	15 min.	45°F.	75°F.	86°F.	83°F.	77°F.
	30 min.	43°F.	70°F.	86°F.	82°F.	77°F.
	45 min.	41°F.	66°F.	83°F.	79°F.	77°F.
4:00 p.m.	1 hour	39°F.	62°F.	82°F.	77°F.	77°F.
5:00 p.m.	2 hours	36°F.	48°F.	74°F.	75°F.	78°F.
6:00 p.m.	3 hours	35°F.	42°F.	66°F.	73°F.	76°F.
7:00 p.m.	4 hours	34°F.	37°F.	58°F.	70°F.	75°F.
Faneuil Hall Market						
9:00 p.m.	6 hours	40°F.	38°F.	33°F.	68°F.	70°F.
10:00 p.m.	7 hours	43°F.	39°F.	33°F.	69°F.	69°F.

Table 0 -- SWEET CORN, Experiment I, 1947

Place and Time of Experiment	Time from Icing	No. 1 crate #1 ice 11 lbs.top; 11 lbs.ctr.	No. 2 crate #2 ice 11 lbs.top; 11 lbs.ctr.	No. 3 crate #3 ice 11 lbs.top; 11 lbs.ctr.	No. 4 crate #4 ice 11 lbs.top; 11 lbs.ctr.	No. 5 crate #1 ice 11 lbs. top only	No. 6 crate Check No ice	Atmospheric Temperature
8/19 Packing Shed 4:00 p.m.	15 min.	65°F.	65°F.	68°F.	72°F.	77°F.	88°F.	88°F.
	30 min.	54°F.	54°F.	52°F.	59°F.	72°F.	88°F.	88°F.
	45 min.	39°F.	40°F.	50°F.	58°F.	72°F.	88°F.	88°F.
5:00 p.m.	1 hour	38°F.	40°F.	50°F.	56°F.	72°F.	88°F.	86°F.
6:00 p.m.	2 hours	36°F.	38°F.	50°F.	47°F.	72°F.	83°F.	83°F.
7:00 p.m.	3 hours	37°F.	40°F.	49°F.	46°F.	71°F.	83°F.	83°F.
8/20 Store Counter 8:00 a.m.	16 hours	52°F.	52°F.	43°F.	38°F.	58°F.	88°F.	79°F.
	15 min.	56°F.						
	30 min.	53°F.						
	45 min.	50°F.						
	17 hours	49°F.						

Table P -- SWEET CORN, Experiment II, 1947

Place and Time of Experiment	Time from Icing	No. 1 crate #1 ice 11 lbs.top; 11 lbs.ctr.	No. 2 crate #1 ice 11 lbs.top; only	No. 3 crate #1 ice, paper liner, 11 lb. top; 11 lb.ctr.	No. 4 crate #2 ice 11 lbs.top; 11 lbs.ctr.	No. 5 crate #3 ice 11 lbs.top; 11 lbs.ctr.	No. 6 crate Check No ice	Atmospheric Temperature
8/20 Packing Shed								
4:00 p.m.	15 min.	38°F.	74°F.	34°F.	52°F.	58°F.	72°F.	71°F.
	30 min.	38°F.	70°F.	34°F.	47°F.	58°F.	72°F.	71°F.
	45 min.	38°F.	70°F.	34°F.	47°F.	52°F.	72°F.	71°F.
5:00 p.m.	1 hour	36°F.	70°F.	34°F.	40°F.	50°F.	72°F.	71°F.
6:00 p.m.	2 hours	36°F.	63°F.	34°F.	36°F.	38°F.	74°F.	70°F.
7:00 p.m.	3 hours	36°F.	61°F.	34°F.	35°F.	37°F.	74°F.	68°F.
8/21 Store Counter								
8:00 a.m.	16 hours	43°F.	55°F.	39°F.	41°F.	36°F.	79°F.	66°F.
Placed on Store Counter Crates Lost Identity	15 min.	48°F.	→	→	→	→	→	
	30 min.	46°F.	→	→	→	→	→	
	45 min.	46°F.	→	→	→	→	→	
	17 hours	45°F.	→	→	→	→	→	

Table Q -- SWEET CORN, Experiment III, 1947

Place and Time of Experiment	Time from Icing	No.1crate #1 ice 22 lb. top only	No.2 crate #2 ice 11 lb.top; 11 lb.ctr.	No.3 crate #3 ice 11 lb.top; 11 lb.ctr.	No.4crate #4 ice 11 lb.top; 11 lb.ctr.	No.5 crate #1 ice Paper liner 11 lb.top; 11 lb.ctr.	No.6 crate Water soaked Only water Temperature 70°F.	No. 7 Crate Check No ice	Atmospheric Temperature
8/27 Packing Shed 6:00 p.m.	15 min.	60°F.	63°F.	60°F.	68°F.	55°F.	71°F.	76°F.	70°F.
	30 min.	52°F.	51°F.	60°F.	68°F.	45°F.	72°F.	76°F.	70°F.
	45 min.	48°F.	51°F.	58°F.	65°F.	45°F.	72°F.	76°F.	70°F.
7:00 p.m.	1 hour	48°F.	49°F.	54°F.	63°F.	42°F.	74°F.	76°F.	70°F.
8:00 p.m.	2 hours	46°F.	46°F.	50°F.	60°F.	38°F.	72°F.	76°F.	68°F.
9:00 p.m.	3 hours	43°F.	44°F.	47°F.	58°F.	37°F.	72°F.	76°F.	67°F.
8/28 Packing Shed 6:00 a.m.	12 hours	55°F.	45°F.	39°F.	33°F.	34°F.	76°F.	73°F.	57°F.
A.&P.Store 9:00 a.m.	15 hours	55°F.	47°F.	47°F.	40°F.	34°F.	74°F.	70°F.	72°F.

Table R -- SWEET CORN, Experiment IV, 1947

Place and Time of Experiment	Time from Icing	No. 1 crate #1 ice 22 lbs. top only	No.2 crate #2 ice 11 lb.top; 11 lb.ctr.	No.3 crate #3 ice 11 lb.top; 11 lb.ctr.	No.4 crate #4 ice 11 lb.top; 11 lb.ctr.	No.5 crate #1 ice Paper liner 11 lb.top; 11 lb.ctr.	No.6 crate Water Soaked Only	No. 7 Crate Check No ice	Atmospheric Temperature
8/28 Packing Shed 6:00 p.m.	15 min.	76°F.	65°F.	72°F.	75°F.	41°F.	77°F.	81°F.	72°F.
	30 min.	76°F.	64°F.	70°F.	72°F.	36°F.	77°F.	81°F.	72°F.
	45 min.	76°F.	64°F.	68°F.	71°F.	36°F.	79°F.	81°F.	72°F.
7:00 p.m.	1 hour	76°F.	61°F.	63°F.	71°F.	36°F.	79°F.	81°F.	72°F.
8:00 p.m.	2 hours	70°F.	50°F.	58°F.	70°F.	34°F.	79°F.	84°F.	70°F.
9:00 p.m.	3 hours	69°F.	48°F.	56°F.	67°F.	33°F.	79°F.	84°F.	68°F.
8/29 Packing Shed 6:00 a.m.	12 hours	65°F.	43°F.	40°F.	36°F.	35°F.	86°F.	88°F.	63°F.
A.&P. Store 9:00 a.m.	15 hours	69°F.	49°F.	42°F.	38°F.	36°F.	87°F.	91°F.	73°F.

Table S -- SWEET CORN, Experiment V, 1948

Place and Time of Experiment	Time from Icing	No. 1 crate #1 ice 22 lbs. top only	No. 2 crate #2 ice 11 lbs.top; 11 lbs.ctr.	No. 3 crate #3 ice 11 lbs.top; 11 lbs.ctr.	No. 4 crate #4 ice 11 lbs.top; 11 lbs.ctr.	No. 5 crate R.ofL. ice 11 lbs.top; 11 lbs.ctr. Paper liner	No. 6 crate Check No ice	Atmospheric Temperature
8/31 Packing Shed 4:00 p.m.	15 min.	72°F.	61°F.	68°F.	75°F.	41°F.	73°F.	71°F.
	30 min.	72°F.	53°F.	63°F.	74°F.	40°F.	73°F.	71°F.
	45 min.	71°F.	51°F.	62°F.	72°F.	38°F.	73°F.	71°F.
	1 hour	71°F.	50°F.	62°F.	72°F.	37°F.	73°F.	71°F.
	2 hours	67°F.	42°F.	59°F.	69°F.	37°F.	73°F.	71°F.
	3 hours	67°F.	41°F.	55°F.	67°F.	37°F.	73°F.	71°F.
9/1 Packing Shed 6:00 a.m.	14 hours	52°F.	49°F.	45°F.	44°F.	38°F.	69°F.	52°F.
	15 hours	52°F.	50°F.	45°F.	44°F.	40°F.	69°F.	52°F.
A.&P. Store 8:00 a.m.	16 hours	55°F.	50°F.	45°F.	44°F.	41°F.	72°F.	53°F.
	17 hours	57°F.	55°F.	49°F.	44°F.	44°F.	72°F.	58°F.
Crates Put in Cold Box	18 hours	57°F.	56°F.	50°F.	47°F.	46°F.	72°F.	62°F.
5:00 p.m.		46°F.	42°F.	41°F.	41°F.	39°F.	---	40°F.

Table T -- SWEET CORN, Experiment VI, 1948

Place and Time of Experiment	Time from Icing	No. 1 crate #1 ice 22 lbs. top only	No. 2 crate #2 ice 11 lbs.top; 11 lbs.ctr.	No. 3 crate #3 ice 11 lbs.top; 11 lbs.ctr.	No. 4 crate #4 ice 11 lbs.top; 11 lbs.ctr.	No. 5 crate #1 ice,paper liner; 10 lbs.top; 10 lbs.ctr.	No. 6 crate Check No ice	Atmospheric Temperature
9/2 Packing Shed 4:00 p.m.	15 min.	78°F.	46°F.	65°F.	77°F.	67°F.	74°F.	71°F.
	30 min.	76°F.	46°F.	62°F.	74°F.	63°F.	74°F.	71°F.
	45 min.	75°F.	46°F.	60°F.	70°F.	62°F.	74°F.	71°F.
5:00 p.m.	1 hour	75°F.	44°F.	55°F.	67°F.	58°F.	74°F.	71°F.
6:00 p.m.	2 hours	73°F.	44°F.	48°F.	62°F.	52°F.	74°F.	70°F.
7:00 p.m.	3 hours	72°F.	41°F.	39°F.	60°F.	46°F.	74°F.	70°F.
9/3 Packing Shed 6:00 a.m.	14 hours	63°F.	54°F.	49°F.	47°F.	42°F.	70°F.	53°F.
A.&P. Store 7:00 a.m.	15 hours	60°F.	54°F.	52°F.	47°F.	43°F.	71°F.	53°F.
8:00 a.m.	16 hours	60°F.	56°F.	54°F.	49°F.	46°F.	72°F.	53°F.

Approved by

Grant B. Snyder

Walter H. Hodge

Adrian H. Lindsey

Date ______________________